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RESEARCH PAPER

Commissioning and quality assurance of Halcyon™ 2.0 linear accelerator

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ABSTRACT

Background: Varian Medical Systems has introduced a new medical linear accelerator called Halcyon™ 2.0, which is based on the ring delivery system (RDS). It is a true IGRT machine having 6MV FFF photon energy. In addition to the planar and MV-CBCT imaging techniques it also has an option of ultra-fast kV-iCBCT which enhances the image reconstruction and improves the visualization of soft tissue. The field portals are shaped by a unique dual layer MLC with special stacked and staggered design which enables high modulation with low radiation leakage. Recently, we have commissioned our first Halcyon 2.0 machine. The aim of this work was to systematically investigate various parameters of a newly installed Halcyon™ 2.0 linear accelerator.

Materials and methods: Detailed measurements were conducted as per various guidelines. Also, the measurements were performed to fulfil the national regulatory requirements. Commissioning data of Halcyon 6 MV-FFF beam was performed in a water tank. For absolute measurements, a 0.6-cc waterproof Farmer chamber and electrometer were used. All relative measurements (PDDs, in-line, cross-line and angular profiles) were performed with 0.0125 cc point chamber.

Results: All the tests were within the acceptable limit. Measured data were compared with factory data as well as the existing medical linear accelerator of the same category. The obtained results were quite satisfactory.

Conclusions: This study summarizes the commissioning experience with Halcyon linear accelerator. Evaluation of mechanical, radiation safety and dosimetric parameters were performed. The obtained parameters were well below the specified tolerance limits.

Key words: radiotherapy; dose; halcyon; tissue; commissioning

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Introduction

Advancement in technology for the treatment of cancer is growing rapidly. Recently, Varian has introduced a new class of linear accelerator referred as Halcyon™ (Varian Medical System, CA). This platform delivers only flattening-filter-free (FFF) photon beam [1–11]. Halcyon is a new clinical linear accelerator designed with a ring-mounted gantry (RDS) enclosed in a bore with single 6 Mega Voltage (MV) FFF beam at 800 MU/min dose rate [12]. Halcyon's treatments are true image guided radiation therapy (IGRT) [13]. It is mandatory to add a kilo-voltage cone beam computed tomography (KV-CBCT) or MV (orthogonal pair or CBCT) imaging field in any treatment plan prior to treatment approval for actual delivery on Halcyon. The MV imaging dose is calculated in the Eclipse (Varian Medical System, CA) treatment planning system prior to optimization which is added in prescribed

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dose [12]. Varian provides a representative beam data set consisting of central axis percentage depth doses (CAPDDs), profiles and output factors. This beam data set was used to configure Halcyon's optimization and dose calculation models (PO & AAA) in the Eclipse treatment planning system (TPS).

Halcyon version 1.0 allows only single isocentre per plan, limiting treatment to its maximum field size of 28 × 28 cm^2, whereas in Halcyon 2.0 two isocentres per plan can be added to extend the treatment length (longitudinal direction) up to 36 cm. Although the True Beam (Varian Medical System, Palo Alto, CA) is adopted worldwide, recently, at our centre we have installed Halcyon™ 2.0 (Varian Medical System, Palo Alto, CA) linear accelerator. Although, limited resources and information is available related to commissioning and quality assurance of Halcyon Linear Accelerator till date. In this article, we have presented the detailed quality assurance (QA) tests related to radiation safety, mechanical, dosimetrical, and MLCs as per various published literatures [14–16]. Measured data were also compared with factory data and the results were quite satisfactory. Baseline data were also generated to check the day to day variation during the use. Daily Machine Performance Check (MPC) is a must before commencement of patient's treatment on the Halcyon, whereas this is optional in the True Beam Machine [17–18]. Halcyon machine is equipped with a radiation beam stopper, hence shielding thickness and room construction cost are reduced drastically.

Dosimetric characteristics of the Halcyon treatment unit were systematically evaluated in terms of central axis percentage depth dose (CAPDD) curves, beam profiles (In line, Cross line and Diagonal), output factors, multi leaf collimators (MLC) leakage and MLC quality assurance (QA) [19–22]. High-resolution diode detectors and ion chambers were used to measure dosimetric data for a range of field sizes from 2.0 × 2.0 to 28.0 × 28.0 cm^2. It is a true IGRT (Image Guided Radiation Therapy) machine equipped with single 6 MV-FFF beam at 800 MU/min fixed dose rate. In addition to the planar and MV-CBCT imaging techniques it has an option of ultra-fast kV-iCBCT which enhances the image reconstruction and improves the visualization of soft tissue [23]. The field portals are shaped by a unique dual layer MLC with special stacked and staggered design which enables high modulation with very low radiation leakage. In Halcyon linear accelerator, the × and Y jaws are absent. There is no field light, optical distance indicator (ODI) and internal lasers for setup. Verification of source to skin distance (SSD) or isocentre matching has to be performed by acquiring MV orthogonal images. Only external laser is provided to set the patients/phantom on the couch.

Materials and methods

Equipment

Halcyon™ 2.0 is a fixed 6 MV-FFF beam linear accelerator, mounted opposite to a beam stopper in a ring geometry enclosed with carbon fibre bore. No bending magnet is used. Halcyon beam is shaped entirely with dual layer independently functioning new generation multi-leaf collimators (MLCs) with stacked and staggered design. The design of MLC offers more efficient treatment and reduced interleaf leakage. Each leaf is 1.0 cm wide projected at the isocenter, and the proximal and distal MLC banks are staggered by 0.5 cm to each other. Hence, the effective resolution of leaf width at isocentre is 0.5 cm. The proximal layer has 29 pairs of leaves whereas the distal layer has 28 pairs. The maximum speed of Halcyon MLCs is 5 cm/sec and gantry is 4 times faster than the existing True Beam machine (15 versus 60 second for one full rotation). Distance from external laser center to the actual physical radiation isocenter is fixed. This shift can be verified through the Machine Performance Check (MPC), which is compulsory to do daily before any treatment to be initiated.

There is no isocentric motion of the couch in this machine, only linear motions are provided. Setting the dosimetry equipment at the machine isocentre is a tricky job as there is no field light, ODI and internal lasers. Setup is performed by first aligning the chamber/radiation field analyzer (RFA) to external lasers mounted on the front panel of the bore, and then loading to the beam center through a pre-determined couch shifts. Chamber position and water level is verified or adjusted using orthogonal MV image pairs. Digital megavoltage imager (DMI-aSi1200) is fixed at 154 cm from the source in the gantry ring just above the MV beam stopper. Imager has a 43 × 43 cm^2 field of view (FOV) with a 1280 × 1280 pixel matrix and image acquisition rate of 25 frames/second at full resolution.

Commissioning data of Halcyon 6 MV-FFF beam was performed in a water tank (3D Scanner, Sun Nuclear Corporation (SNC, USA). For absolute measurements, a 0.6-cc waterproof Farmer chamber (SNC600) and electrometer (Sun Nuclear, USA) calibrated at MD Anderson Dosimetry Laboratory, USA were used. All relative measurements (CAPDDs, In-line cross-line and angular profiles) were performed with 0.0125 cc point chamber (SNC 125). The corrections for effective point of measurement were applied.

Calibration of halcyon unit

The Halcyon system software requires the user to select one of the three geometries for which 1 MU is normalized to 1 cGy. Calibration of the machine is restricted to these three different geometries and associated dose rates. This can be confirmed by measuring the dose to the reference point for a 10 × 10 cm^2 field size:

- 100 cm SSD, 1.3 cm depth (d_{max}), max dose rate: 800 MU/min;
- 95 cm SSD, 5.0 cm depth, max dose rate: 740 MU/min;
- 90 cm SSD, 10.0 cm depth, max dose rate: 600 MU/min.

It is extremely important that the selected calibration geometry on the machine and in the treatment planning system (TPS) are the same, otherwise, it may lead to major treatment error. We have calibrated our machine according to the first setting.

Output factors and surface dose

Output factors (OF) were acquired using a SNC600 farmer type cylindrical ion chamber for field sizes ranging from 2 × 2 to 28 × 28 cm^2. For smaller field sizes (≤ 4 × 4 cm^2) a small volume chamber was also used (SNC125) to correct the volume effect. OFs were normalized to a 10 × 10 cm^2 field size. Percentage surface dose (PSD) was determined using an edge detector (SNC, USA) for the maximum field size.

Mechanical tests

Mechanical tests of the couch, gantry and collimator were performed in accordance with recommendations from standard clinical linear accelerators commissioning protocols of the national regulatory body.

Radiation dosimetry tests

To evaluate various dosimetry parameters central axis depth dose, inline, cross-line and diagonal profiles were needed for various field sizes. CAPDD profiles were taken for the field sizes ranging from 2 × 2 to 28 × 28 cm^2 with the interval of 2 and were determined by MLC settings (as there are no jaws in the machine). In-plane and cross-plane profiles were taken for the above mentioned field sizes at 1.3 cm (d_{max}), 5 cm, 10 cm, 20 cm and 30 cm depths. The chamber position was corrected for the effective point of measurement in the acquisition software. Chamber polarity (k_{pol}) and saturation (k_s) correction factors were also determined.

Beam quality specifiers (TPR20/10) and PDD $(10)_x$ were determined in accordance with TRS-398 [24] and TG-51 [25] protocol, respectively. PDD data at various depths and field sizes were tabulated and compared. Penumbra was quantified and compared to other Halcyon machines for the transverse and radial beam profiles. For FFF beams, however, the penumbra definition of the spatial distance between the 80% and 20% values does not apply, and the normalization technique introduced by Pönisch et al. [26] was employed. The penumbral widths were quantified after rescaling the FFF beam profiles to the ratio of the dose values at the inflection points in the penumbral regions between the flattened (FF) and un-flattened (FFF) beams.

Dynamic MLC tests

Average and maximum MLC transmission were measured using a farmer-type ionization chamber (collecting volume = 0.60 cm^3) at nominal treatment distance (NTD). According to TG-50 [27], the average leaf transmission should be < 2%. Accuracy of positioning and leaf speed modulation of MLC was verified in both the static and dynamic mode of delivery, using Picket fence tests [28]. Electronic portal imaging device (EPID) was used in the measurements.

Radiation safety

Halcyon unit has a ring-mounted 6 MV-FFF linear accelerator with a beam-stopper. The head leakage specification is 0.1% and the beam stopper is specified for 0.1% transmission of 6 MV. Vault shielding evaluation and associated considerations were carried out as per the national regulatory body and also with reference to NCRP Report No. 151

[29]. The head leakage measurements were also carried out in patient plane and other than patient plane. Radiation area survey is also carried out after successful installation of the unit.

Results

Mechanical tests

Mechanical tests on the couch and multi leaf collimators (MLC) were performed. All the parameters were well below their tolerance values specified by the national regulatory body. The test results were consistent with the other Halcyon machine as well as with available literature.

Couch

Mechanical tests were performed on the Halcyon couch. All the obtained parameters were tabulated in Table 1. All the parameters were well below the specified tolerance limit. Some of the mechanical tests on the couch were not applicable to the Halcyon machine. ODI test could not be performed as the machine does not have any optical field light. The couch rotational accuracy was also not performed as the motion is limited to only vertical, lateral and longitudinal directions.

Collimator

Mechanical tests were also performed on MLCs and the obtained results were tabulated in Table 2. Some of the mechanical tests of MLCs were not applicable to the Halcyon machine. All the measured parameters were well below their specified tolerance limit.

Calibration of the Halcyon unit

Absorbed dose at reference depth in water was determined according to the TRS-398 protocol [24]. SSD setup (100 cm at water surface) was used and 1 MU is normalized to 1 cGy for the reference field size of 10×10 cm^2. Alignment of the ion chamber at the reference depth was verified with orthogonal images of MV-EPID.

Output factors and surface dose

After correction in setup conditions for small fields, minimal variation was observed among relative photon output factors. Figure 1 shows the output factors plotted for various field sizes. The green line in the figure indicates the raw output factor obtained using a 0.6 cc farmer chamber plotted against field size. The output factor for small field size is seen to have considerable varia-

Table 1. Mechanical tests parameters of couch

Sr. no.	Tests	Tolerance	Observations
1.	Minimum level of table top above the floor	≤ 80 cm	62.5 cm
2.	Longitudinal motion of the couch	≥ 70 cm	165.5 cm
3.	Vertical motion of couch from the isocenter	> 40 cm below the isocenter	47.4 cm below the isocenter
4.	Minimum linear speed of table top	≤ 1 cm/sec	0.43 cm/sec
5.	Accuracy of longitudinal motion of table top	0.3 cm for speed ≤ 2.5 cm/sec	< 0.1 cm
6.	Accuracy of lateral motion of the table top	0.3 cm for speed ≤ 2.5 cm/sec	< 0.1 cm
7.	Accuracy of vertical motion of table top	0.3 cm for speed ≤ 2.5 cm/sec	< 0.1 cm
8.	Table top sag at isocenter when loaded with 135 kg distributed over 2 cm through isocenter	≤ 2 mm	≤ 2 mm
9.	Couch transmission	0.9798	0.9796

Table 2. Mechanical tests parameters of multi leaves collimator (MLC)

Sr. no.	Tests	Tolerance	Observations
1.	Accuracy of angular scale of collimator	0.5° at ≤ 1°/sec	0.1°
2.	Gap between isocenter and end of accessory mount	≥ 30 cm	50 cm
3.	Shift in isocenter due to collimator rotation	≤ 2 mm in dia	0.6 mm
4.	Accuracy of leaf position	± 1 mm	0.11 mm
5.	Reproducibility of leaf position	± 1 mm	0.58 mm

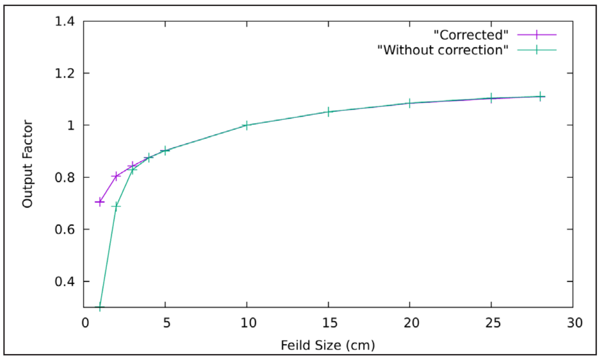

Figure 1. Output factor of Halcyon machine

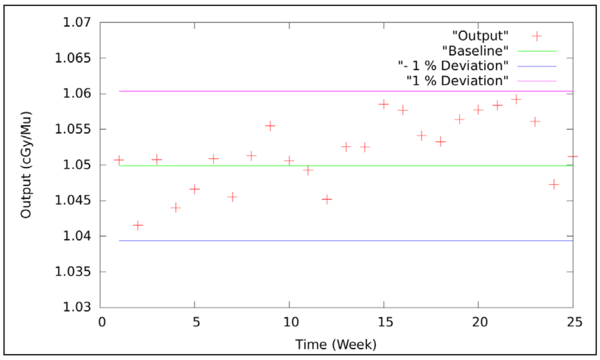

Figure 2. Output constancy check of Halcyon machine

tion from the predicted data. This deviation is due to the large size of the detector volume and lack of electronic equilibrium. The purple line shows the output factor plotted against the field size after applying the correction which was derived using a method called Daisy Chaining [14]. The measured percentage surface dose for the maximum field size (28 × 28 cm^2) was 63.55% using the edge detector and normalised to the depth of maximum dose.

Radiation dosimetry tests

Energy stability check (TPR20/10)

The energy check was carried out in a water tank (RFA system). Table 3 shows the consistency of TPR20/10 values measured at different time in a day with a coefficient of variation (CoV) of 0.2576.

Output constancy

Temporal output stability was reported for Halcyon 6-FFF photon beam from the date of commissioning. Output at different time in a day was measured and tabulated (Tab. 4). No significant variation in output was observed during the different time in a day. The calculated value of coefficient of variation was 0.0872. The central axis output measurements over a period of 6 months were also analysed and plotted (Fig. 2). The trend of the graph demonstrates the normal behaviour with time. The observed maximum deviation in output was 0.6% from the institutional baseline limit of ±1% with the normal calibration.

Consistency in percentage depth dose

Mean energy levels of FFF beams are lower than those of corresponding flattened beams. We have

Table 3. Consistency of TPR20/10 at different time in a day

Energy	Time of measurements	TPR 20/10	Difference (%)	Average	Standard deviation	Coefficient of variation (%)
6MV FFF	T1 (10 AM)	0.6267	Ref	0.6247	0.001609348	0.257619288
	T2 (12 Noon)	0.6245	–0.35			
	T3 (3 PM)	0.6232	–0.56			
	T4 (6 PM)	0.6264	–0.05			

Table 4. Output constancy at different time in a day for 300 MU and 10 × 10 cm^2 field size

Energy	Time of measurements	MR (nC)	Output [cGy/MU]	Difference (%)	Average	Standard deviation	Coefficient of variation (%)
6MV FFF	T1 (10 AM)	34.803	1.0007	Ref	1.0032	0.000876	0.08728
	T2 (12 Noon)	34.87	1.0026	0.19			
	T3 (3 PM)	34.833	1.0015	0.14			
	T4 (6 PM)	34.81	1.0008	0.01			

Table 5. Consistency of PDD at 10 cm depth for 5×5 and 10×10 cm^2 field sizes

Field size	Energy	Sr. no.	PDD at 10cm depth	Average	Standard deviation	Coefficient of variation (%)
5 × 5	6 FFF	1	58.71	58.7325	0.035939764	0.061192295
		2	58.74			
		3	58.78			
		4	58.7			
10 × 10	6 FFF	1	62.79	62.8	0.060553007	0.096421986
		2	62.86			
		3	62.83			
		4	62.72			

measured the dose at 10 cm depth for the field sizes of 5×5 and 10×10 cm^2 for halcyon 6-FFF beam. From Table 5 it is observed that the dose at 10 cm depth is consistent with the published data of the True Beam machine for the same energy [14].

Linearity of MU

Accuracy of radiation dose delivery is limited by the dose nonlinearity of smaller MUs. This is significant in intensity modulated radiotherapy, involving small segment sizes. Linearity was performed over a wide MU range starting from 2 to 200 MU. This MU range was separated into two regions as a small MU range (< 5 MU) and higher MU range (> 4 MU). In the small and higher MU range, the measured coefficient of linearity (COL) was 0.52% and 0.46%, respectively, as shown in Table 6 (A and B). These values are much below the tolerance limit of 5.0% and 2%, respectively [30]. Also from Table 6 it was observed that at the low MU range the COL value is higher as compared to the higher range.

Depth dose curves and profiles

For the flattening filter free beams, d_{max} is located closer to the surface than the flattened beams. The central axis depth dose curves for Halcyon 6 MV-FFF beam were measured for various field sizes. Figure 3 demonstrates the plot between relative doses versus field sizes varies from 2×2 to 28×28 cm^2. Measured value of d_{max} for Halcyon 6 MV-FFF beam was 1.3 cm. This is approximately 2 mm closer to the surface than 6 MV unflattened beams. We compared the measured CAPDD curve and central axis beam profile with factory data (TPS) and found them to be in a good agreement as shown in Figure 4.

Table 6AB. MU linearity tests

A. For > 4 MU			
Sr. no.	MU (U)	Mtr.Reading (nC) (L)	Factor S (= L/U)
1	5	0.597	0.1194
2	6	0.714	0.1190
3	7	0.833	0.1190
4	8	0.948	0.1185
5	9	1.071	0.1190
6	10	1.187	0.1187
7	15	1.777	0.1184
8	20	2.369	0.1184
9	30	3.55	0.1183
10	50	5.917	0.1183
11	70	8.287	0.1184
12	100	11.83	0.1183
13	150	17.74	0.1183
14	200	23.66	0.1183
		S Max	0.1194
		S min	0.1183
		Coefficient of linearity (%)	0.4627

B. For < 5 MU		
MU (U)	Mtr.Reading (nC) (L)	Factor S (= L/U)
2	0.241	0.1205
3	0.359	0.1197
4	0.477	0.1193
	S Max	0.1205
	S min	0.1193
	Coefficient of linearity (%)	0.5214

The profiles of unflattened beams have their maximum dose on the central axis and decrease

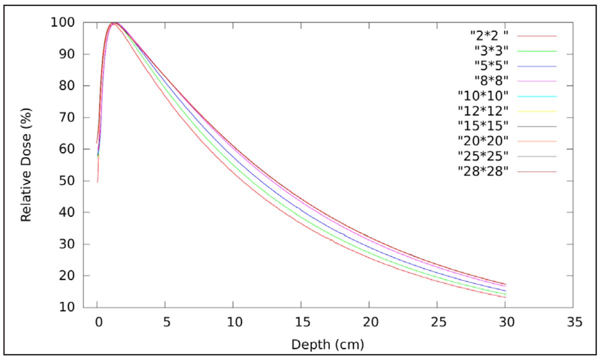

Figure 3. PDD curve at various field sizes of Halcyon 6 MV-FFF beam

gradually toward the field edge. This effect becomes more pronounced with increasing beam energy and field size. We have measured the in-line, cross-line and diagonal profiles for 6 MF-FFF beam of Halcyon machine. The profiles at various field sizes and depths were plotted and shown in Figure 5. Smaller variations in profile with depth were observed with Halcyon FFF beam. Various parameters, such as symmetry and penumbra, were evaluated for small as well as large field sizes. For small field size (3×3 cm^2) consistency in symmetry was observed and tabulated (Tab. 7). No significant variation in symmetry value was noted for both in-line and cross-line profile.

Table 8 summarises the symmetry and penumbra obtained for field sizes 5×5, 10×10, 20×20 and 28×28 cm^2 both in-plane and cross-plane geometry at 10 cm depth. From the table it was observed that the penumbra for Halcyon is sharper for both the in-line and cross-line plane in contrast to other existing traditional Clinac machines with the same 6 MV-FFF energy [14]. A slight widening of the penumbra with increasing field size was observed. The arrangement of jaws at different levels in the linear accelerator head causes the difference in the penumbra value. The replacement of jaws with dual layer MLC in Halcyon, results in approximately equal penumbra in both in-line and cross-line planes.

MLC tests

Leakage measurements

The measured percentage values of the maximum and average MLC transmission were 0.03% and 0.01%, respectively. The maximum and average percentages of head leakage in the patient and other than patient plane were 0.01%, 0.004% and 0.11%, 0.02%, respectively.

DMLC output with gantry angle

In this test, the machine output was measured at gantry angles of 0, 90, 180 and 270 degrees. At each gantry angle, the RapidArc DMLC QA plan was performed with a 4×28 cm^2 DMLC field and 0.5 cm slit size. Total 300 MU was delivered at the dose rate of 800 MU/min. The obtained output measurements were summarised in Table 9. The obtained values were well below the tolerance limits.

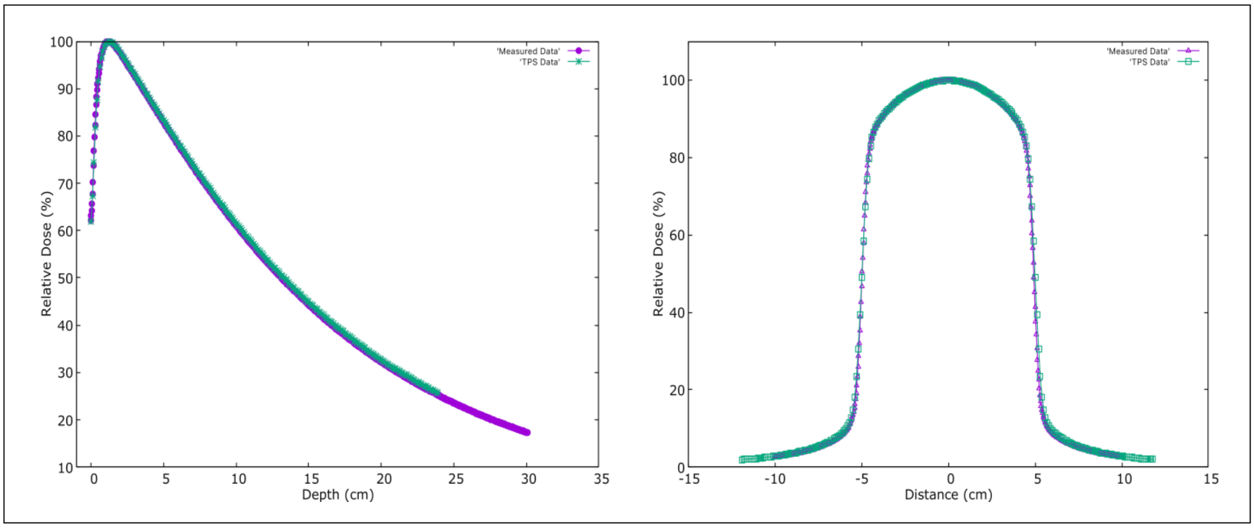

Figure 4. Measured versus TPS comparison of PDD curve (Lt) and profile (Rt) for 10×10 cm^2 field size

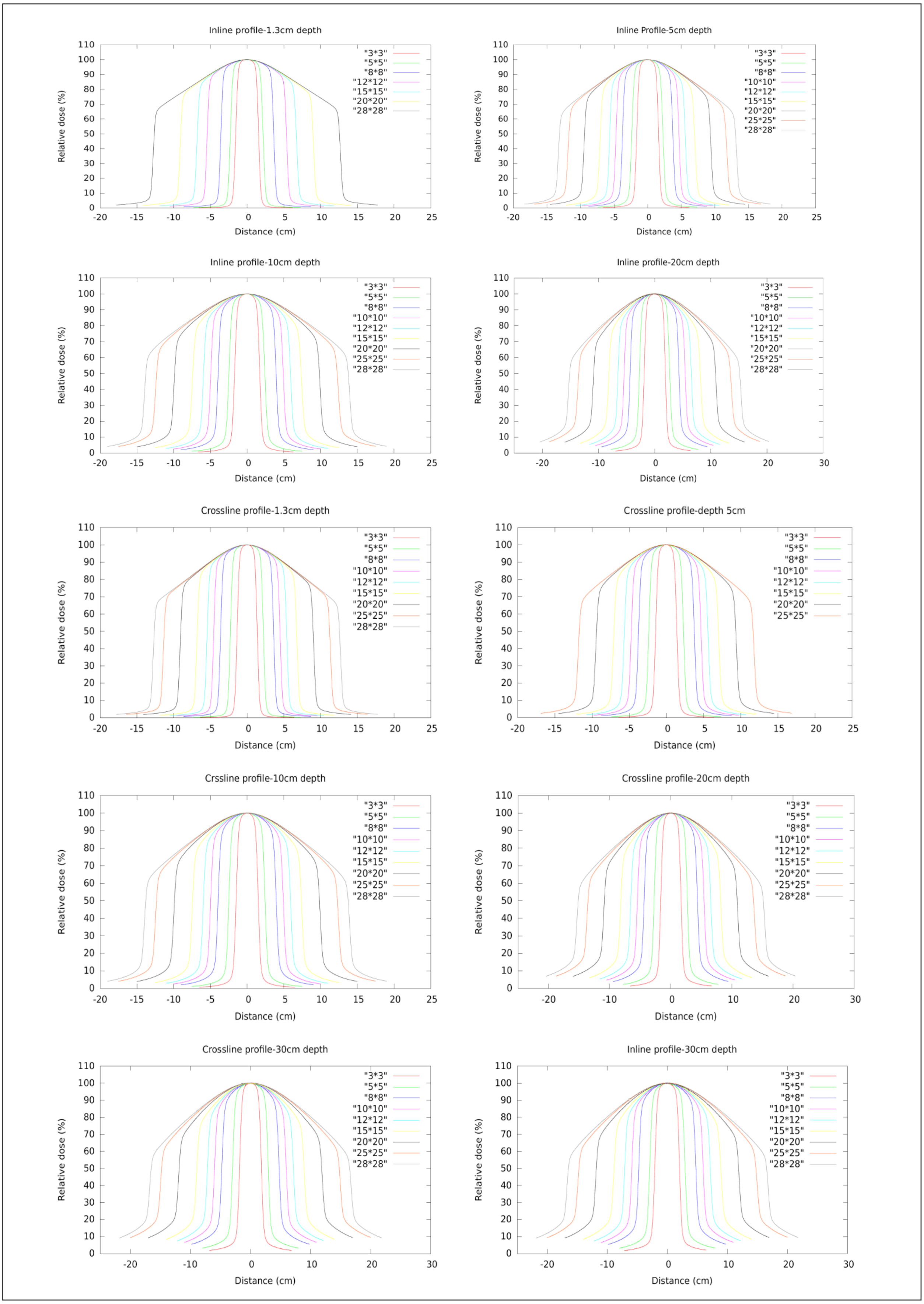

Figure 5. In-line and Cross-line profiles at various field sizes

Table 7. Consistency of symmetry for 3 × 3 cm at 10 cm depth

Measurement plane	Energy	Sr. no.	Symmetry (%)	Difference (%)	Tolerance (%)
In-plane	6FFF	1 (baseline)	100.7		1%
		2	100.97	0.27	
		3	101.17	0.47	
		4	100.31	0.39	
Cross-plane	6FFF	1 (baseline)	100.4		1%
		2	100.49	0.09	
		3	100.41	0.01	
		4	101.26	0.86	

Table 8. Symmetry and Penumbra analysis of various field sizes

No.	Photon beam energy	Field Size	Symmetry	Penumbra
1	6 MV FFF	5 × 5 cm	Inline/Crossline: 0.64%/0.36%	Inline: –4.5 mm, +4.6 mm Crossline: –4.5 mm, +4.2 mm
2	6 MV FFF	10 × 10 cm	Inline/Crossline: 0.26%/0.22%	Inline: –4.3 mm, +4.1 mm Crossline –4.5 mm, +4.3 mm
3	6 MV FFF	20 × 20 cm	Inline/Crossline: 0.34%/0.35%	Inline: –4.9 mm, +4.8 mm Crossline –5.2 mm, +4.9 mm
4	6 MV FFF	28 × 28 cm	Inline/Crossline: 0.64%/0.52%	Inline: –5.5 mm, +5.2 mm Crossline –5.7 mm, +5.2 mm

Table 9. DMLC output at various gantry angle

Gantry angle (degrees)	Relative output	Deviation (%)	Tolerance (%)
0 (Ref)	0.2903	0.00	
90	0.2927	0.8267	±3%
180	0.2922	0.6545	±3%
270	0.2928	0.8612	±3%

Static and dynamic picket fence

For static picket fence 300 MU at the dose rate of 800 MU/min was delivered, whereas 480 MU was used at same dose rate for rotational version of it. Fences were shaped with slit opening of 0.1 cm, 10 pickets in all and 1.5 cm gap between each other. Also, the intentional errors were introduced and evaluated. All the corresponding images of fences were displayed in Figure 6 (A–F). Shaping was done by distal leaves (proximal leaves retracted).

Fences were displayed in the central part of the field between × = –7 cm and × = +7 cm. Quantitative and qualitative study was performed on the obtained Picket Fence images. The obtained static and dynamic fence results were summarised in Table 10 and 11, respectively. From the table it was observed that the values were well below their tolerance limit.

Discussions

This study summarizes the commissioning experience of Halcyon linear accelerators. Evaluation of mechanical, radiation safety, dosimetric and MLC parameters were performed. The obtained parameters were well below the specified tolerance limits. Results also demonstrated the excellent agreement with the other Halcyon machine as well as with published results [31–32]. MLC transmission and head leakage values showed a drastic reduction in radiation leakage and also secondary malignancies [22]. This reduction is due to the Halcyon's new generation MLCs. The new generation high speed MLCs and improved version of imaging systems enhance the accuracy of treatment delivery and quality of care. MV as well as KV images are used

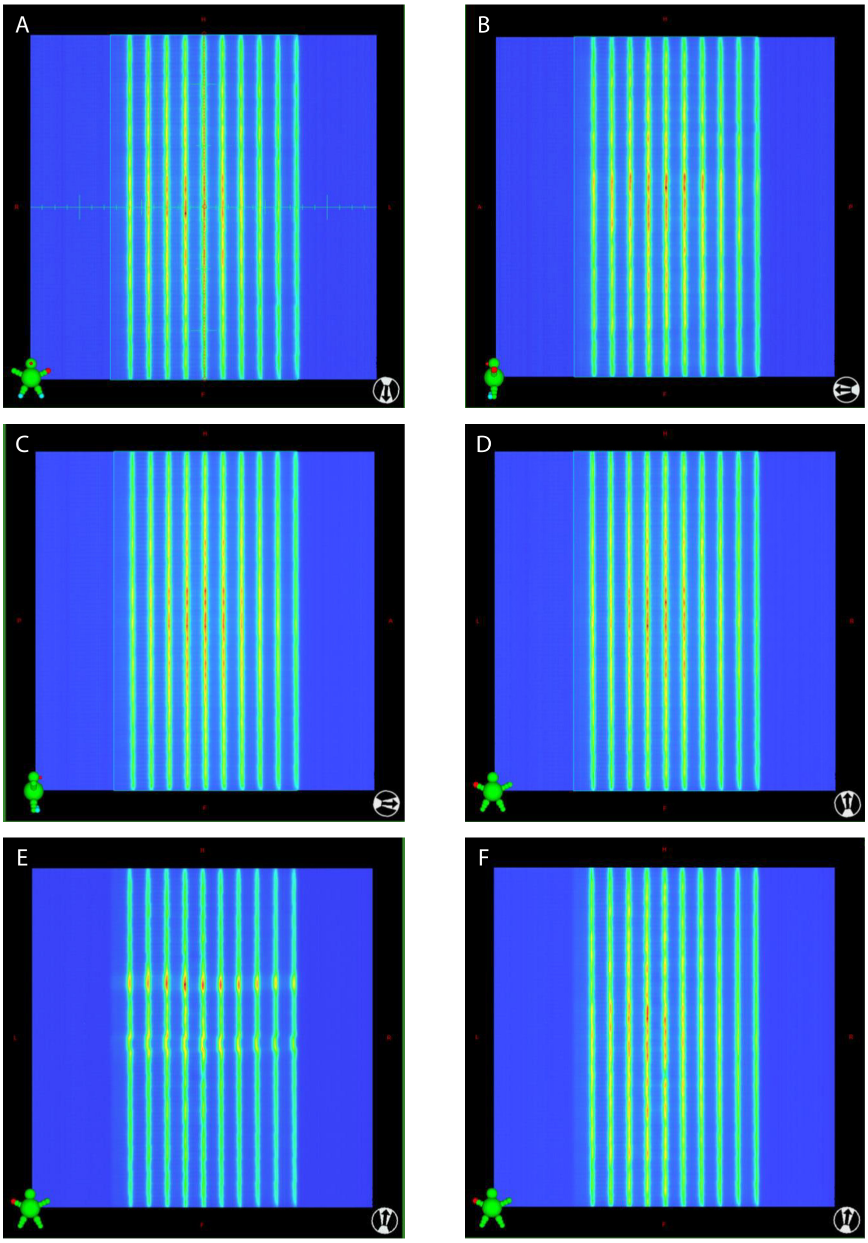

Figure 6. Picket fence test images at: **A**. 0°; **B**. 90°; **C**. 270°; **D**. 180° gantry angles; **E**. During rapidArc delivery (179° to 187° gantry); **F**. With intentional error of 0.5 and 0.2 mm at the same gantry rotation

Table 10. Static picket-fence tests results

Gantry angle (degree)	Maximum deviation [mm]	Tolerance [mm]
0 (Ref)	0.17	1
90	0.47	1
180	0.17	1
270	0.25	1

Table 11. Rotational picket-fence results

Gantry angle (degree)	Maximum deviation [mm]	Tolerance [mm]
179 to 187	0.62	1

to verify the positional accuracy of the patient on the treatment couch on a day to day basis. In the absence of light field, optical-distance-indicator and mechanical distance measuring instruments which are present and used in Clinac series linear accelerators, accurate positioning of a water tank, solid water phantoms, detectors as well as patients relies on the Halcyon couch largely on the acquired MV and KV images.

Halcyon 2.0 offer both megavoltage (MV) as well as kilovoltage (KV) imaging systems with advanced iCBCT which make images less noisy and provide a better visualization of soft tissues. The KV imager in Halcyon2.0 is fixed perpendicular to the treatment beam axis as usual. Halcyon's CBCT has limited field size of 28 cm in length and 50 cm field of view (FOV). There are some limitations with Halcyon 2.0, such as the size of the treatment field portal and respiratory gating. We hope these limitations could be addressed in future versions with the capability of treating a spectrum of patients who need radiotherapy. Commissioning of Halcyon2.0 linear accelerator presents new challenges related to its completely new type of setup geometry and the absence of a light field and mechanical distance measuring devices. A new method was used to position the water phantom and other dosimetry equipment on the couch top.

Eclipse treatment planning system for Halcyon is preloaded with a representative beam model. Varian provided beam data consist of PDDs curve, central axis beam profiles and output factors. As the system is preloaded, the need for generating extensive beam data sets during the commissioning process could be reduced. It is our first experience with the Halcyon, hence, we collected a vast data set during commissioning. That includes safety data, dosimetry data, mechanical data and imaging (MV & KV) QA data set. We analysed and compared the measured versus representative beam data set provided by Varian and found no major disagreements. We also compared it with the other institute's Halcyon's commissioning data sets. It was observed that both were in good agreement. The user cannot edit/modify or fine-tune the beam data model with respect to the measured data set. Instead of editing the Eclipse beam data library, the user has to tune the Halcyon machine to perform as per TPS data. The preconfigured systems have opened a new paradigm for Medical Physicists on how to approach the subject of acceptance testing, commissioning and day to day quality assurance of new generation medical linear accelerators.

Conclusions

Parameters related to mechanical, radiation safety, dosimetrical and multi-leaf collimators of Halcyon's 6 MV-FFF beams were systematically measured. The central axis depth dose curve, beam profiles, relative output factors, DMLC parameters and other dosimetric data were systematically analysed. The measured commissioning data show consistency and are in a good agreement with the other units with the same energy. The commissioning data provided us with valuable insights and reliable evaluations on the characteristics of the new generation treatment delivery system. The systematically measured data might be useful for future reference.

Conflict of interests

The authors declare that they have no conflict of interests or personal relationships that could have appeared to influence the work reported in this paper.

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