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ORIGINAL ARTICLE

Comparison of Measured and Calculated Halcyon 3.0 Beam Data

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OBJECTIVE

The Halcyon comes with a reference beam data (RBD) set including percentage depth dose (PDD) curves, profiles, and output factors. Varian generates a pre-configured beam model in Eclipse treatment planning system (TPS) using this RBD. The aim of the current study is to validate RBD set of Halcyon 3.0, newly installed in our institute.

METHODS

The PDD and lateral dose profiles were measured for open fields with sizes from 4×4 cm^2 to 28×28 cm^2 in a water tank using a semiflex ionization chamber. The PDD and profiles were calculated with the AAA v17.1 in Eclipse for the same field sizes as described in ion chamber measurements. The depth of maximum dose (d_{max}), PDD value at depth of 10 cm, penumbra, field size, and lateral distance from the central axis at 90%, 75%, and 60% dose points of profile were analyzed.

RESULTS

The difference of d_{max} values was 0.08 cm for all PDDs. A good agreement was obtained between calculated and measured PDD10 with a maximum difference of 0.35%. The measured field size and penumbra values indicated an excellent agreement with calculated values with a maximal discrepancy of 0.17 cm and 0.50 mm for all field sizes, respectively. The discrepancies between calculated and measured lateral distances for all field sizes were within 0.20 mm.

CONCLUSION

The TPS-calculated data using pre-configured beam model for Halcyon 3.0 were in good agreement with the measurements.

Keywords: Beam data verification; golden beam data; halcyon; TPS verification.

INTRODUCTION

In 2017, Varian introduced a novel linear accelerator, named Halcyon (Varian Medical Systems, Palo Alto CA). The single-energy Halcyon, with an enclosed O-ring gantry, has a 6 MV flattening filter free (FFF) photon beam at 800 MU/min maximum dose rate.[1] The rotation of the gantry is 4 times faster than a C-arm linac, such as the TrueBeam. The maximum field size is 28×28 cm^2 for a single isocenter. Moreover, it is possible to extend the field (longitudinal direction) size up to 38.5 cm using two isocenters per plan in Halcyon v3.0. In this platform, there are no beam-shaping jaws. The system includes stacked and staggered dual-layer multileaf collimators (MLC). The proximal layer consists of two banks with 29 leaves of 1 cm width at iso-

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center each. The distal layer consists of two banks with 28 leaves of 1 cm width at isocenter each. The proximal leaf pairs are offset from the distal leaf pairs by 5 mm to minimize leaf transmission. The maximum speed of the leaves is 5 cm/s which means 2 times faster than MillenniumTM 120-leaf MLC.[2] Performing the Daily Machine Performance Check (MPC) is mandatory before delivery of a patient's treatment in the Halcyon.[3] The system offers true image-guided radiation therapy with IMRT and VMAT. Before approving the treatment plan for delivery, kilovoltage or megavoltage cone beam computed tomography (KV-CBCT or MV-CBCT) or MV orthogonal pairs must be added in the plan. An image acquisition is compulsory before each treatment delivery in the Halcyon system. The delivery time of Halcyon is relatively reduced thanks to faster gantry rotation and speed of leaf motion compared with C-arm linacs.

The installation and commissioning of the Halcyon can be performed rapidly because the manufacturer offers reference beam data (RBD) set including the percentage depth dose (PDD), lateral dose profiles, output factors, and pre-defined beam model in the Eclipse treatment planning system (TPS) (Varian Medical Systems, Palo Alto, CA).[4] Performing the verification of (RBD) is recommended by the AAPM TG 106 as beam data can differ from linac to linac although the same vendor supplies the same model.[5] The aim of the current study is to validate RBD of the Halcyon v3.0 linear accelerator, newly installed in our institute, by comparing measured data using an ionization chamber with calculated data using a pre-defined beam model in TPS.

MATERIALS AND METHODS

This study was approved by the Academic Coordination Community of Istanbul University Institute of Oncology (Date and issue: 24.08.2023-2065990).

Measurements

The measurements were made using 6 MV-FFF photon beams by utilizing the Varian Halcyon v3.0 system. The output of the machine was calibrated to deliver 1 cGy/MU under reference conditions; source to skin distance (SSD)=100 cm, field size = 10×10 cm^2, and at depth=d_{max} (1.3 cm). Before measuring the beam data, the output of the machine was checked using RW3 water-equivalent slab phantom and a 0.6 cc farmer-type ionization chamber according to the TRS-398.[6] The setup was made with the following steps as there is no light field, optical distance indicator, and isocenter lasers in the Halcyon. The alignment of the phantom was performed with the bore lasers and then loaded to the beam center. The chamber position was verified with two orthogonal MV images. $TPR_{20,10}$ at 10×10 cm^2 was also measured for 6MV-FFF.

A PTW MP3-M water tank (PTW-Freiburg, Germany) and a semiflex 0.125 cm^3 ionization chamber (type 31010, PTW-Freiburg, Germany) were used for all beam data measurements. The PDD and lateral dose profiles were obtained for open fields with sizes from 4×4 cm^2 to 28×28 cm^2 determined by MLC settings. The SSD was set to 100 cm. The lateral dose profiles were measured at a depth of 10 cm under the same setup conditions. All data were smoothed and normalized to maximum value for each PDD curve. The normalization was conducted to the central-axis value for each profile. The beam data analysis was performed with Mephysto mc2 software.

Calculations

Vendor provides RBD set and configures dose calculation models using these data in Eclipse TPS. In this study, the virtual water phantom with size of 40×40×40 cm^3 was created in Varian Eclipse v17.1 TPS (Varian Medical Systems, Palo Alto, CA). The PDD and profiles were calculated with the AAA v17.1 algorithm for the same field sizes as described in ion chamber measurements. The dose for each calculation was set at 100 MU. The calculation grid size was 2.5 mm. The PDDs were normalized to their maximum values for each field size. The profiles were normalized to the corresponding central axis value for each field size.

Analysis

The calculated dose distribution with AAA algorithm for PDD and profiles were compared with our measurements. The PDD value at 10 cm (PDD_{10}), which is beam quality specifier according to TG-51, and depth of dose maximum (d_{max}) were recorded.

The field width and penumbra were analyzed under profiles. Usually, the radiation field size of FF photon beams is specified at 50% of the isodose level of profile. This definition cannot be implemented for the field size of FFF photon beams because the 50% isodose level occurs at the high dose gradient part of the profile. The determination of the field size and penumbra was carried out according to the Atomic Energy Regulatory Board of India Task Group (AERB-TG) recommendations.[7]

The inflection point (IP) is defined as the midpoint on either side of the high gradient region (sharply de-

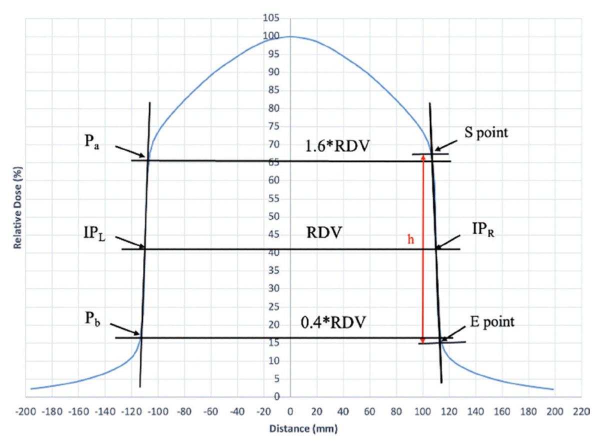

Fig. 1. Schematic diagram for determining inflection points, field size, and penumbra.
RDV: Reference dose value

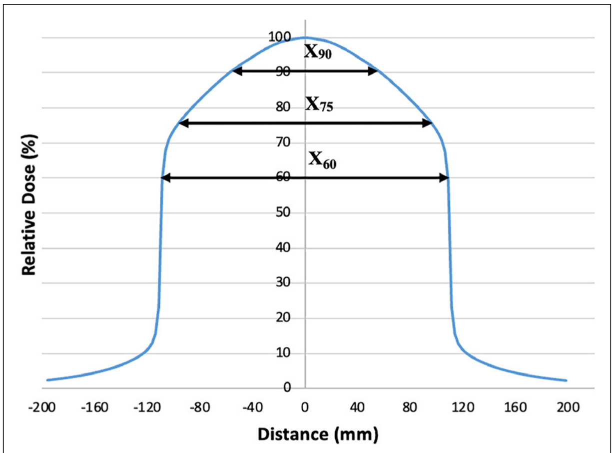

Fig. 2. Schematic diagram for determining lateral distances at 90%, 75%, and 60% dose points on the beam profile.

scending part) of the beam profile. The starting point (S) and ending point (E) of the high gradient region of the beam profile are identified. The vertical separation between S and E is the height (h) of the high gradient region of the beam profile. The point at h/2 is considered as the point of inflection. The lateral separation between left and right IP (IP_L and IP_R) along the central axis is taken as field width. For determining penumbra, dose value at IP was taken as reference dose value (RDV). Points Pa and Pb are located at 1.6 and 0.4 times of RDV, respectively. Lateral separation between Pa and Pb on either side of the profile is measured as penumbra.[7] Figure 1 shows all definitions. The field size and penumbra were calculated using graphical manual calculations method for all profiles. The lateral distance from the central axis at 90%, 75%, and 60% dose points on either side of the beam as the degree of unflatness was also analyzed, based on the protocol in AERB-TG (Fig. 2).

RESULTS

The $TPR_{20,10}$ was found to be 0.620. The normalized PDDs measured and calculated for each field size are presented in Figure 3. The d_{max} and PDD_{10} of the PDDs are summarized in Table 1. The difference of d_{max} values was found to be 0.08 cm for all PDDs. A good agreement was obtained between calculated and measured PDD10 with a maximum difference 0.35%. This disagreement within 2% conforms to the MPPG5.a recommendation.[8] As it can be seen easily in Figure 3, the main dose discrepancies are in surface dose for all field sizes.

The normalized central axis lateral dose profiles are measured and calculated for each field size at depth of 10 cm are shown in Figure 4. The comparison of radiation field size and geometric penumbra values of measured and calculated central axis dose profiles at 10 cm depth for SSD=90 are presented in Table 2. The measured field size and penumbra values indicated an excellent agreement with calculated values with a maximal discrepancy of 0.17 cm and 0.5 mm for all field sizes, respectively. The lateral distance from the central axis at 90%, 75%, and 60% dose points on either side of all measured and calculated profiles for SSD=90 is summarized in Table 3. The differences between calculated and measured lateral distances for all field sizes were within 0.20 mm.

DISCUSSION

The Halcyon v3.0, the new clinical linear accelerator of Varian, was installed in our institute recently. The linac comes with a RBD set including PDDs, profiles, and output factors. Varian generates pre-configured optimization and dose calculation models in Eclipse v17.1 TPS using this RBD, and thus, extensive beam data collection for generating the beam model is not needed. The user performs the collection of certain beam data to check the pre-installed data in TPS.[9] As it is our first experience with the Halcyon, the verification of the PDDs and profiles calculated by the pre-loaded beam model in Eclipse v17.1 TPS was performed by comparing with water tank measurements and presented in this study.

The comparison was made between the calculated PDDs and profiles with AAA v17.1 in TPS and the measured data with a semiflex ionization chamber in

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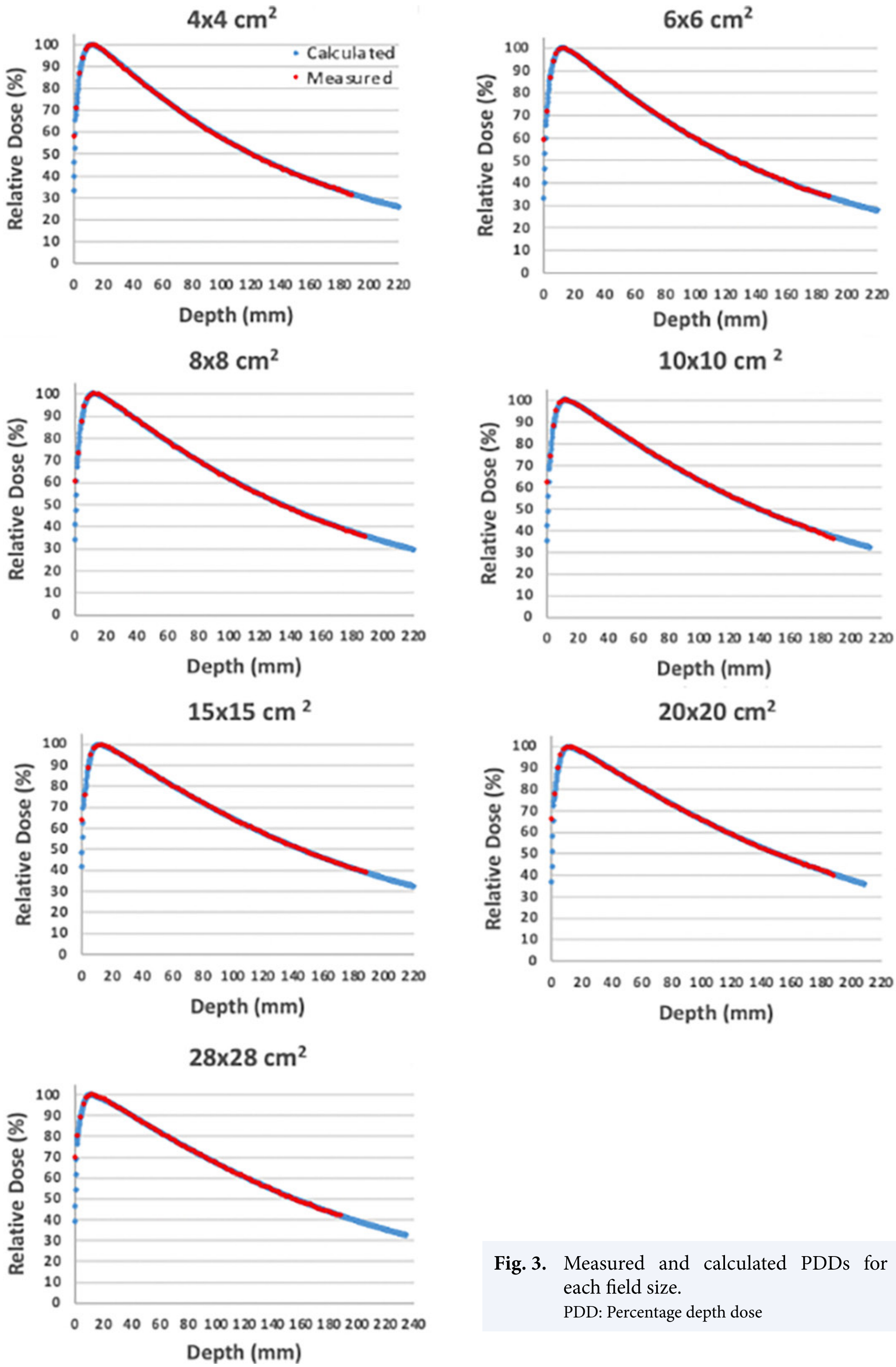

Fig. 3. Measured and calculated PDDs for each field size.
PDD: Percentage depth dose

Table 1 The d_{max} and PDD_{10} of the PDDs between measured and calculated

	Field size (cm²)						
	4×4	**6×6**	**8×8**	**10×10**	**15×15**	**20×20**	**28×28**
d_{max}(cm)							
Measured	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Calculated	1.12	1.12	1.12	1.12	1.12	1.12	1.12
Difference	0.08	0.08	0.08	0.08	0.08	0.08	0.08
PDD_{10} (%)							
Measured	57.40	60.00	61.50	62.90	64.70	66.00	67.00
Calculated	57.58	59.79	61.51	62.80	64.79	66.05	67.04
Difference	0.31	0.35	0.02	0.16	0.14	0.08	0.06

PDD: Percentage depth dose

Table 2 Field size and penumbra analysis

Actual field size (cm²)	Field size (cm²)			Penumbra (mm)		
	Measured	**Calculated**	**Diff.**	**Measured**	**Calculated**	**Diff.**
4×4	3.91	4.06	0.15	3.92	3.42	−0.50
6×6	5.94	6.04	0.10	4.48	4.24	−0.21
8×8	7.94	7.97	0.03	4.70	4.50	−0.20
10×10	9.97	10.04	0.07	4.95	4.80	−0.15
15×15	15.03	14.90	−0.13	5.88	5.78	−0.10
20×20	20.10	20.20	0.10	7.29	7.25	−0.04
28×28	28.12	27.95	−0.17	8.27	8.23	−0.04

Diff.: Difference

Table 3 Lateral distance from the central axis at 90%, 75%, and 60% dose points on either side for measured and calculated profiles

	X90% (cm)			X75% (cm)			X60% (cm)		
Field size (cm²)	**Measured**	**Calculated**	**Diff.**	**Measured**	**Calculated**	**Diff.**	**Measured**	**Calculated**	**Diff.**
4×4	3.19	3.39	0.20	3.55	3.75	0.20	3.78	3.95	0.16
6×6	5.04	5.23	0.19	5.55	5.75	0.20	5.79	5.89	0.10
8×8	6.58	6.71	0.13	7.47	7.62	0.15	7.77	7.87	0.10
10×10	7.73	7.85	0.12	9.46	9.65	0.19	9.75	9.89	0.14
15×15	9.68	9.52	−0.16	14.09	14.25	0.16	14.70	14.83	0.13
20×20	10.45	10.49	0.05	17.85	17.71	−0.15	19.56	19.74	0.17
28×28	11.36	11.25	−0.12	20.74	20.56	−0.17	27.10	27.08	−0.02

Halcyon v3.0 for field size ranging 4×4 cm^2 to 28×28 cm^2. This study reported that the measured data indicated an excellent agreement with the Eclipse TPS calculated data. As expected, the main dose differences are in surface dose in PDDs for all field sizes because TPSs cannot calculate the surface dose accurately.[10]

Netherton et al.[9] verified the RBD for pre-clinical Halcyon v1 of two institutions independently. The PDD and profiles were measured with CC13 ionization chamber and diodes (<4×4 cm^2) at one institute and CC04 at the other institute (2×2 cm^2–28×28 cm^2). The maximum difference between RBD and measured data was found to be 0.6% in PDD values for field sizes greater than 2×2 cm^2 at each institute. They found the IP by plotting the first derivatives of the profiles for all field sizes to calculate penumbra. The penumbra was specified by calculat-

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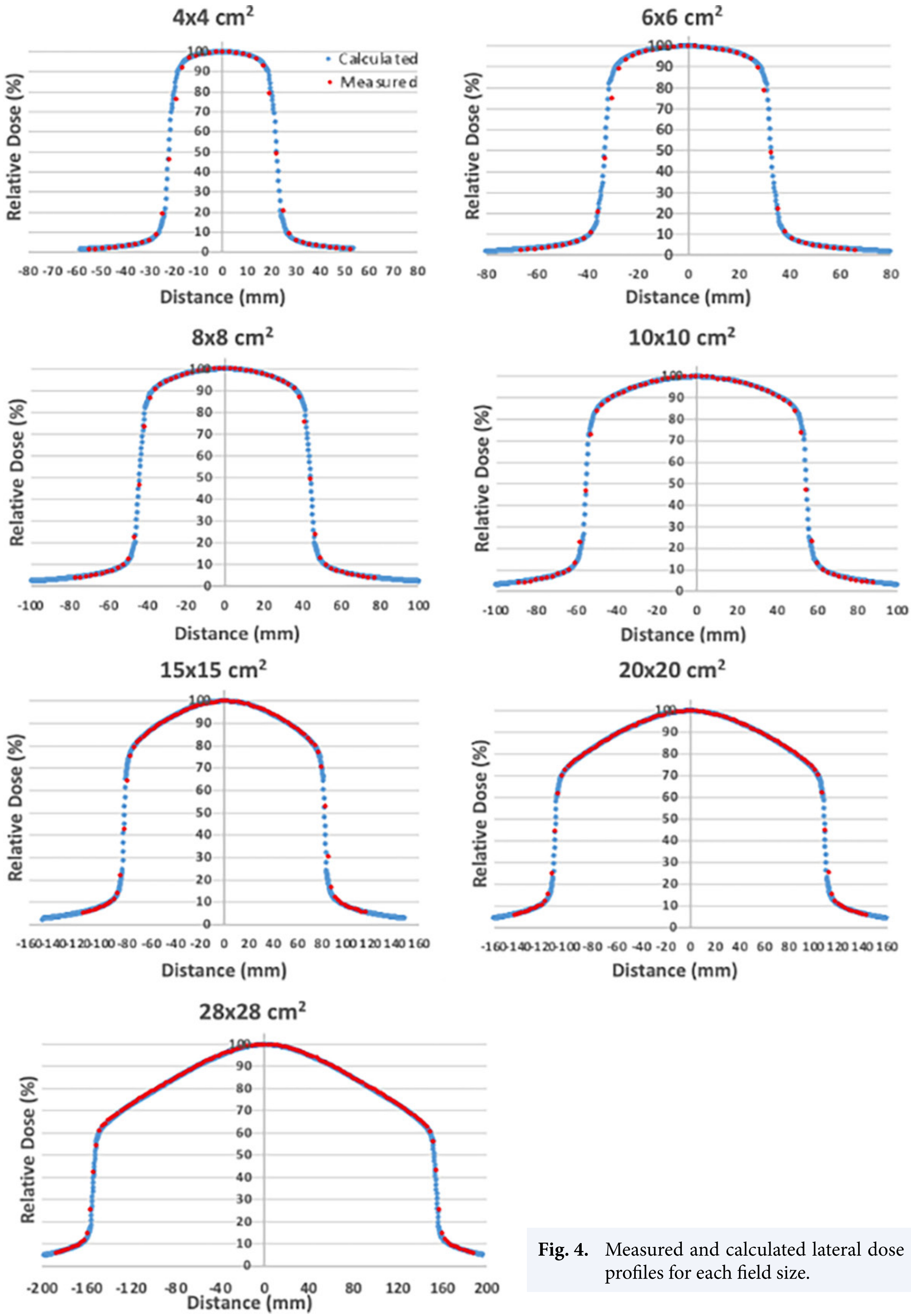

Fig. 4. Measured and calculated lateral dose profiles for each field size.

ing the full-width half maximum of each first derivative curve. The penumbra was 4 and 8 mm for field size 2×2 cm^2 and 28×28 cm^2 in the RBD set at depth of 10 cm, respectively. The measured penumbra compared to RBD within 2 mm for each field size in their study.

Tamura et al.[11] conducted a study to validate the supplied reference beam profiles (RBPs) for Halcyon beam model. They measured PDD and profiles using a CC13 ionization chamber (>4×4 cm^2) and an Edge (≤4×4 cm^2) at SSD=90 cm. As a result of their comparison between RBPs and measured profiles, they found that the discrepancies of d_{max}, PDD10, and penumbra were within 1 mm, 0.3%, and 0.8 mm. The PDD_{10} value at 10×10 cm^2 was 61.5% in their study.

Pathak et al.[12] measured all beam data using a water tank with a 0.0125 cc point chamber in Halcyon v2.0. They did not observe major differences between measured and factory data for PDDs and profiles. They also measured $TPR_{20,10}$ with 0.6 cc farmer chamber and found it of 0.625.

The above-mentioned studies are compatible with our study results which showed an excellent agreement between measured data and TPS calculated data using on pre-installed beam model for Halcyon v3.0. The penumbra values were found to be 3.92 and 8.27 mm from measured profiles for 4×4 cm^2 and 28×28 cm^2, respectively. The measured penumbra widths matched the calculated penumbra widths with a maximum difference of 0.5 mm for all field sizes at a depth of 10 cm. The measured PDD_{10} was 62.90% for 10×10cm^2 at SSD=100 cm, with a 0.16% discrepancy from calculated one (Varian specification 63%±1). The $TPR_{20,10}$ was found to be 0.620 in our study which is consistent with the previous published study.[12] The $TPR_{20,10}$ was measured to be 0.666 and 0.632 for 6MV and 6X-FFF in TrueBeam linac in Shende's research.[13] Removing the flattening filter from linear accelerator head results in a softer photon energy spectrum causing a steeper reduction in dose at depths. Shende et al.[13] measured the lateral distance of 90%, 75%, and 60% of the profile to quantify the degree of unflatness beam in TrueBeam 6X-FFF and found to be 9.97, 17.27, and 19.66 for 20×20 cm^2 field size, respectively. Our results agreed with this study.

CONCLUSION

The TPS calculated data using pre-configured beam model for Halcyon v3.0 were in good agreement with the measurements. This beam model can be used without performing any modification for Eclipse TPS.

Peer-review: Externally peer-reviewed.

Conflict of Interest: All authors declared no conflict of interest.

Ethics Committee Approval: The study was approved by the Academic Coordination Community of Istanbul University Institute of Oncology (no: 2065990, date: 24/08/2023).

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