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RESEARCH PAPER

Determination of small-field output factors for beam-matched linear accelerators using various detectors and comparison of detector-specific output correction factors using IAEA Technical Report Series 483 protocol

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ABSTRACT

Background: Beam matching is widely used to ensure that linear accelerators used in radiotherapy have equal dosimetry characteristics. Small-field output factors (OF) were measured using different detectors infour beam-matched linear accelerators and the measured OFs were compared with existing treatment planning system (TPS) Monte Carlo algorithm calculated OFs.

Materials and methods: Three Elekta Versa HD™ and one Elekta Infinity™linear accelerators with photon energies of 6 MV flattening filter (FF), 10 MVFF, 6 MV flattening filter free (FFF) and 10 MVFFF were used in this study. All the Linac'swere beam-matched, Dosimetry beam data were ± 1% compare with Reference Linac. Ten different type of detectors (four ionizationchambers and six diode detectors) were used for small-field OF measurements.The OFs were measured for field sizes of 1 × 1 to 10 × 10 cm^2, and normalized to 10 × 10 cm^2 field size. The uncorrected and corrected OFs were calculated from these measurements. The corrected OF was compare with existing treatment planning system (TPS) Monte Carlo algorithm calculated OFs.

Results: The small-field corrected and Uncorrected OF variations among the linear accelerators was within 1% for all energies and detectors. An increase in field size led to a reduction in the difference between OFs among the detectors, which was the case for all energies. The RSD values decreased with increasing field size. The TRS 483 provided Detector-specificoutput-correction factor (OCF) reduced uncertainty in small-field measurements.

Conclusion: It is necessary to implement the OF-correction of small fields in a TPS. Special care must be taken to incorporate the corrected small-field OF in a TPS.

Key words: output factor; small field; linear accelerator; treatment planning system

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Introduction

The aim of advanced radiotherapy treatment techniques is the delivery of highly conformal and accurate doses to tumors, while reducing the normal tissue dose. The treatment flexibility and efficiency of radiotherapy departments could be improved if linear accelerators (linacs) were dosimetrically identical, and patients could be treated using any linac without the need to adjust their

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treatment plans. Identical dosimetric characteristics can be achieved using beam-matched linacs [1]. In the literature, there are many studies available for beam-matched linacs from different vendors [1–8]. Beam matching is performed during a customer acceptance procedure (CAP), ensuring the clinically acceptable degree of accuracy between linacs. A satisfactory beam match is determined by ensuring that the beam data percentage depth dose at 10cm depth (PDD_{10}), beam profiles, output, output factors (OF), and multi-leaf collimator (MLC) leaf transmission factor for a linac is matched as closely as possible to one set from a reference linac. The treatment planning system (TPS) beam data are generated based on the reference beam data set. To limit the exposure to toxic levels of radiation in normal tissues and organs at risk in Stereotactic Radiosurgery (SRS), Stereotactic Body Radiotherapy (SBRT) and Stereotactic Radiotherapy (SRT) plans, a large number of small fields are used [9]. These small fields are created using an MLC or a circular cone collimator. There are various challenges related to the measurement of small-field dosimetry due a rapid dose fall-off at the beam edges and partial occlusion of the primary radiation source [10–14]. Small-volume and high-spatial-resolution detectors are required to measure small-field OFs [15–16]. There is currently no ideal detector available to measure small fields, due to the engineering of detector design, tolerance limits and perturbation factors. The lack of lateral charge particle equilibrium (LCPE), volume average and non-tissue equivalence of detector materials prompts the need for detector-specific output correction factors (OCF) [10–11, 17].

Detector-specific OCF that have been obtained for various detectors are available in the literature, which were determined based on any of the following empirical methods: (i) use of an empirical comparison between the field and reference detector signal ratio to generate the correction factor [16–21]; (ii) use of a numerical simulation model such as Monte Carlo to generate the correction factor [22–24]; (iii) use of a semi-empirical approach. Most researchers work with this last method, comparing measurement and simulation to generate the correction factor [17, 23–24].

The American Association of Physicists in Medicine (AAPM) and the International Atomic Energy Agency (IAEA) published the Technical Report Series (TRS-483) protocol for small-field dosimetry [10]. The protocol contains a set of detector-specific OCF for detector manufactured by different vendors, such as. PTW Dosimetry (Germany), IBA Dosimetry (Germany), Sun Nuclear Corporation (United States), and Standard Imaging (United States).

Smith et al., 2020, evaluated the TRS483 protocol recommended OF for 6MV FF beam using nine detectors in Elekta SRS cone and MLC [19]. However, in that literature the data is not available for 6MV FFF, 10MV FFF and 10MV FF beams. Also, the small field OCF data is not available for Elekta Medical Systems (United Kingdom) beam matched linacs. Most of Institute TPS algorithms were commissioned based on uncorrected OFs data. In our Institute, the four-beam matched Linac's have been in clinical use since 2016. This TPS-Monti Carlo algorithm was commissioned based on uncorrected OFs data. Hence in this study, the 6 MV and 10 MV [flattening filter (FF) and flattening filter free (FFF)] photon beams small-field OFs were measured and compared using ten detectors. The corrected OFs were compared to the existing TPS-Monti Carlo algorithm calculated OFs.

Materials and methods

Elekta agility multi-leaf collimator

Three Elekta Versa HD™ (Elekta AB, Stockholm, Sweden) and an Elekta Infinity™. (Elekta AB, Stockholm, Sweden) linacs are in clinical use in our institution. These four linacs are equipped with photon beam of 6, 10, and 15 MV FF beam, and the Versa HD linear accelerators have the additional features of 6 MV and 10 MV FFF photon beams. All four linacs have in-built 160-leaf Agility Multi-leaf collimators. The lower jaw is a tungsten block and MLC leaves are the upper jaw, their widths are 5 mm, and they cover a maximum field size of 40×40 cm^2 at the isocenter. The linacs PDD, beam profile, MLC transmission and OF are beam-matched as per the Elekta customer acceptance test (CAP) guidelines.

Detectors

Ten different types of detectors, four ionization chambers and six diode detectors (three shielded and three unshielded diodes) were used for

Table 1. Physical characterizes of detectors

Label	Type	Active volume dimensions	Material	Effective atomic number (Z_{eff})	TRS-483 detector specific OCF minimum equivalent square filed (S_{clin}) used in these studies*
IBA CC13	Air filled-cylindrical ionization chamber	Dia — 6 mm Height — 5.8 mm Volume —0.13 mm^3	Air	7.6	2.06
IBA CC01	Air filled-cylindrical ionization chamber	Dia — 2 mm Height — 3.6 mm Volume — 0.1 mm^3	Air	7.6	1.16
IBA PFD 3G	Shielded diode	Disk Dia — 2 mm Thick — 0.06 mm Volume — 0.19 mm^3	Silicon	14	1.16
IBA EFD 3G	Unshielded diode	Disk Dia — 2 mm Thick — 0.06 mm Volume — 0.19 mm^3	Silicon	14	1.16
PTW PINPOINT 31014	Air filled-cylindrical ionization chamber	Dia — 2 mm Height — 5 mm Volume — 15 mm^3	Air	7.6	1.16
PTW SEMIFLEX 31010	Air filled-cylindrical ionization chamber	Dia — 5.5 mm Height — 6.5 mm Volume — 125 mm^3	Air	7.6	2.06
PTW DIODE P 60016	Shielded diode	Disk Dia — 1.13 mm Thick — 2.5 µm Volume — 0.0025 mm^3	Silicon	14	1.16
PTW DIODE E 60017	Unshielded diode	Disk Dia — 1.13 mm Thick — 30 µm Volume — 0.03 mm^3	Silicon	14	1.16
PTW DIODE SRS 60018	Unshielded diode	Disk Dia — 1.13 mm Thick — 250 µm Volume — 0.3 mm^3	Silicon	14	1.16
SUN NUCLEAR EDGE DIODE	Shielded diode	Square 0.8 × 0.8 mm^2 Thick — 30 µm Volume — 0.019 mm^3	Silicon	14	1.16

*TRS-483 suggested maximum detector specific output correction factors (OCF) for the equivalent square field size 8 cm

OF measurements. The physical characteristics of the detectors are shown in Table 1. The PTW Unidos and IBA Dose 1 electrometers were used for measurement. The bias voltage for the ionization chambers was +300 V, while that of the diode was 0 V. For all measurements, the ion chambers and edge diode were positioned perpendicular to the central axis of the beam and all other diodes were positioned parallel to the central axis of the beam. The measurement setup used in this study is shown in Figure 1. All the detectors are used to measure OF reading for 1 × 1 cm^2 to 10 × 10 cm^2 field size, except IBA CC01 and PTW Semiflex, because detector specific OCR factor for 1 × 1 cm^2 field size is not available in the TRS-483 protocol. These detectors OF measurements were done for 2 × 2 cm^2 to 10 × 10 cm^2 field sizes.

Equivalent square field (S_{clin}) measurement

The detector-specific output correction factor is provided in the TRS 483 protocol (Tab. 26 and 27) these were calculated based on energy and equivalent square small-field sizes [10]. Geometrical field size was converted into equivalent square small-field size (S_{clin}): equivalent square fields were calculated for field sizes ranging from 1 × 1 to 10 × 10 cm^2 for the four linear accelera-

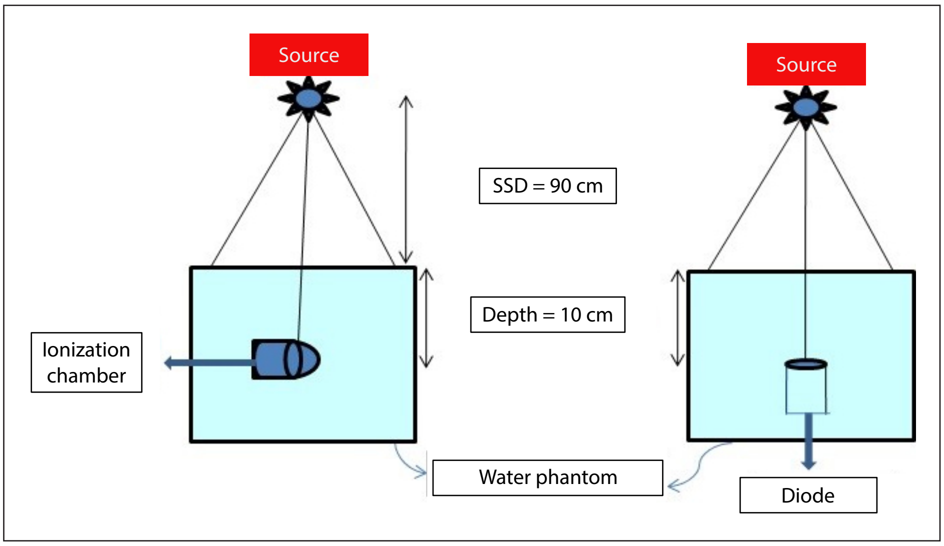

Figure 1. Detectors position in the central axis of the beam. SSD — source to surface distance

tors, as suggested by the TRS 483 protocol, using formula (1).

$$S_{clin} = \sqrt{A * B} \qquad (1)$$

In a square field of size **A** and **B**, the radiation field full width at half maximum (FWHM) is in-line and cross-line direction perpendicular to the central axis of the beam, at a source to surface distance (SSD) of 90 cm and a depth of 10 cm. The IBA CC01 was used for S_{clin} measurements and initial commission beam data were measured used the same detector.

Output factor measurement

Output factor measurements were performed using the IBA Dosimetry (Blue phantom[2]) with myQA Accept software. The phantom scanning dimensions were: 480 mm (L) × 480 mm (W) × 410 mm (H), with a positional reproducibility of ± 0.1 mm. The measurements were performed at an SSD of 90 cm and a depth of 10 cm, and the detector was positioned at the isocenter. The OF was measured for field sizes between 1 × 1 and 10×10 cm^2 using the ten different types of detectors, with the 10 × 10 cm^2 field size as a reference size for all photon energies. The measurements were performed in all four linacs. Pre- and post-irradiation leakage was noted before each measurement. For each energy, the measurement was repeated three times with 100 monitor unit (MU). The output consistency and beam quality ($TPR_{20,10}$) were monitored every day before measurements were obtained. The uncorrected OFs were calculated using formula (2).

$$Uncorrected\ OF = \frac{Detector\ reading\ for\ given\ field\ size}{Detector\ reading\ for\ reference\ field\ size} \qquad (2)$$

Detector-specific output correction was applied to each detector and the corrected output factor was calculated.

$$Corrected\ OF = \frac{Detector\ reading\ for\ given\ field\ size}{Detector\ reading\ for\ reference\ field\ size} \times Detector\ specific\ OCF * \qquad (3)$$

*Correction factor provided in TRS 483 protocol (Tab. 26 and 27).

Relative standard deviation

Relative standard deviation (RSD) was calculated for the uncorrected and corrected output factor values for the various detectors, with different beam energies (6MVFF, 6MVFFF, 10MVFF, and 10MVFFF) and field sizes [19].

$$RSD = \frac{Standard\ deviation}{Mean} \times 100 \qquad (4)$$

Comparison of measured and TPS-generated OFs

The Elekta Medical Systems (Monaco 5.51.10), UK TPS beam data was commissioned for Monte Carlo, Pencil Beam, and collapsed cone convolution algorithms. The OF was calculated for field sizes of 1 × 1 to 10 × 10 cm^2 with a 10 Gy dose at an SSD of 90 cm and a depth of 10 cm [24]. The water phantom with the dimension of 30 cm × 30 cm × 30 cm was created in the TPS to calculate OF using the Monte Carlo algorithm. The dose per MU was calculated for each field size, which was then normalized to a 10 × 10 cm^2 field size. The corrected OFs were calculated from measurement and compared with the TPS Monte Carlo algorithm calculated OFs.

Results

Equivalent square field (S_{clin}) measurement

Equivalent square field size was calculated for each field size using formula (1). Table 2 shows the calculated equivalent square field sizes for 6 MV FF, 6 MV FFF, 10 MV FF, and 10 MV FFF photon beams from all four linacs. For all energies S_{clin} field size increases with decrease in geometric field size.

Output factor measurement

The OF measurements were performed for field sizes ranging from 1 × 1 to 10 × 10 cm^2 using ten different types of detectors. An OF measurement was not performed for the detectors IBA CC13 and PTW semi flex (0.125 cc) for a field size of 1 × 1 cm^2 because a detector-specific OCF for these detectors was not available in the literature [14]. The uncorrected and corrected OFs were calculated using formulas (2) and (3). Figures 2–4 and 5 show variations in uncorrected and corrected OFs with respect to field size for the 6 MV FF, 10 MV FF, 6 MV FFF, and 10 MV FFF photon beams, respectively. The IBA EFD detector shows the maximum variation in the uncorrected OF with 1 × 1 cm^2 field size for all the energies. For energies and detectors, the difference in OF reduces after applying the detector specific correction factor compared to uncorrected OF. Among the entire beam matched linacs the difference in OF is within 1% for all detectors.

Relative standard deviation

The percentage of RSD was calculated for the uncorrected and corrected OF values. Tables 3–5, and 6 show the calculated RSD values for the uncorrected and corrected OFs for the 6 MVFF, 10 MVFF, 6 MVFFF, and 10 MVFFF photon beams, respectively. The maximum RSD was observed for the field size 1 × 1 cm^2 among all the detectors and energies. After applying the detector-specific OCF, the RSD value reduced to 2.25 ± 0.05 (%) for 1 × 1cm^2 field size less than 1% for ≥ 2 × 2 cm^2 field size for all energies.

Comparison of measured and TPS-calculated OFs

The TPS calculated OFs were compared with measured OFs. The percentage of variation

Table 2. The calculated equivalent square filed sizes for all four linear accelerators

Geometrical field size length [cm]	Equivalent square field (S_{clin}) [cm]													
	Versa HD1				Versa HD2				Versa HD3				Infinity	
	6 MV FF	6 MV FFF	10 MV FF	10 MV FFF	6 MV FF	6 MV FFF	10 MV FF	10 MV FFF	6 MV FF	6 MV FFF	10 MV FF	10 MV FFF	6 MV FF	10 MV FF
1	1.21	1.16	1.18	1.17	1.20	1.16	1.22	1.18	1.18	1.17	1.24	1.19	1.22	1.20
2	2.11	2.09	2.06	2.08	2.13	2.12	2.08	2.10	2.11	2.10	2.12	2.09	2.09	2.10
3	3.08	3.07	3.05	3.07	3.11	3.09	3.08	3.10	3.10	3.08	3.09	3.07	3.09	3.08
4	4.06	4.01	4.04	4.02	4.07	4.04	4.02	4.05	4.08	4.07	4.09	4.09	4.11	4.01
5	5.02	5.00	5.03	5.0	5.04	5.03	5.01	5.02	5.04	5.03	5.05	5.02	5.01	5.03
6	6.02	6.01	6.00	5.98	6.05	6.02	6.03	6.03	6.04	6.02	6.04	6.05	6.03	6.02
7	7.01	6.95	6.97	6.99	7.00	6.99	6.99	6.98	7.03	7.01	7.04	7.03	7.00	7.00
8	7.98	7.97	7.98	7.96	7.99	7.96	7.97	7.98	8.01	7.98	7.99	8.00	7.98	7.99
9	8.99	8.97	8.99	8.96	8.98	8.98	8.95	8.96	8.99	8.98	8.96	8.97	8.96	8.98
10	9.97	9.95	9.95	9.97	9.98	9.96	9.92	9.93	9.96	9.94	9.95	9.97	9.99	9.95

FF — flattening filter; FFF — flattening filter free

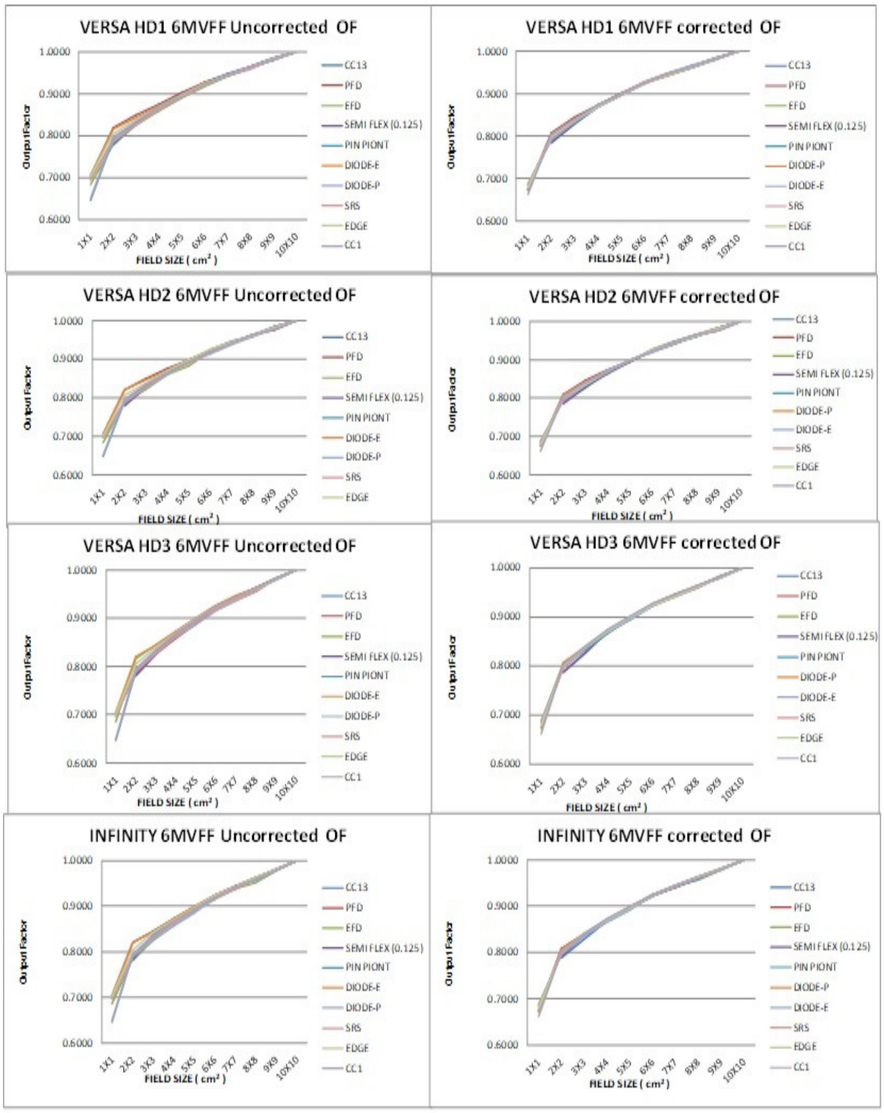

Figure 2. The uncorrected and corrected output factors (OF) for the 6 MV flattening filter (FF) photon beam

with respect to field size was observed for field sizes ranging from 1 × 1 to 10 × 10 cm^2. Figures 6–8 and 9 show the percentage differences in OF with respect to field size for the 6 MVFF, 10 MVFF, 6 MVFFF, and 10 MVFFF photon beams, respectively. Wolfgang et al., 2018, shows that the action limit for the measured and TPS algorithm generated OF was ± 3% field size ≤ 2 × 2 cm^2 and ± 2% field size ≥ 2 × 2 cm^2. Our results show less than 2% Varian for all the field size, which is in good agreement with the above finding. [24]. All the energies unshielded diode OF shows the more variation with respect to TPS OF. The TPS beam data was commissioned using CC01 ionization chamber.

Discussion

Flexibility in radiotherapy treatment would be improved if patients could be moved from one linac to another without changing their treatment plans. This may be achieved by employing beam-matched linacs that have the same dosimetric parameters. In this study, we used four beam-matched Elekta linacs which contained the same type of Agility MLC collimator. Small-field OF was measured and compared for four beam-matched linacs using different types of detectors. The measured OFs between the beam-matched linacs were within 1% for all energies and detectors.

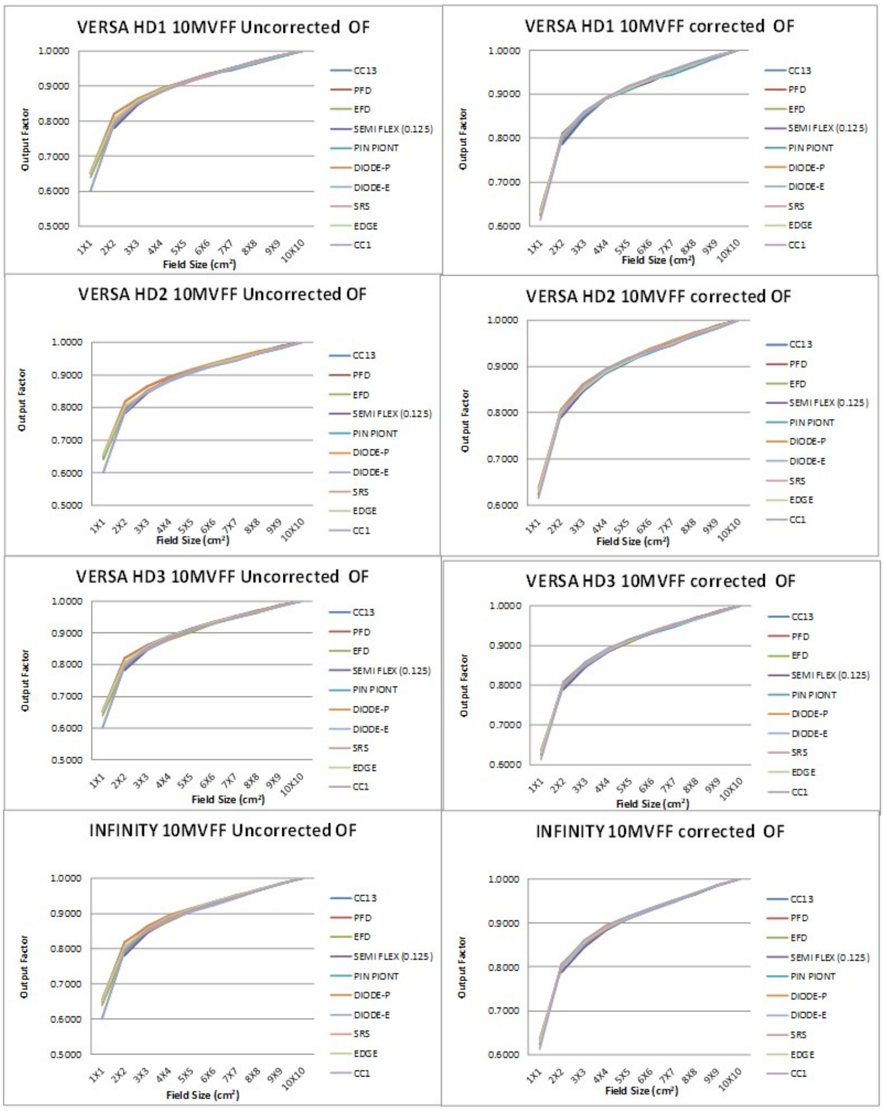

Figure 3. The uncorrected and corrected output factors (OF) for the 10 MV flattening filter (FF) photon beam

Wolfgang stated that when using shielded diodes for the dosimetry of small fields with FF- and FFF-beams, the correction factors determined for FF-beams could not necessarily be applied to FFF-beams, particularly in the case of higher energies. There was no significant difference between the dose responses of other detectors used for FF- and FFF-beam small-field measurement. For the ten detectors used in this study, there were no significant differences in dose response between the detectors, with the similar exception of the shielded diode [25]. For all energies, the unshielded diode showed over-response for the 1×1 cm^2 uncorrected OF measurement. Among the eight detectors used for the 1×1 cm^2 field size OF measurement, the IBA EFD Diode showed the maximum variation of 4.79 % for a 6MV FF beam. Similar OF values were observed for a field size $\geq 2 \times 2$ at all energies and for all ten detectors. An increase in field size led to a reduction in the OF differences between detectors for all energies.

FWHM was observed in Elekta SRS cone using high spatial resolution monolithic silicon detector array (DUO) and compared with EBT3 film and IBA SFD measurement, the result showed the agreement of ± 0.5 mm. The FWHM increased with decrease in cone size [16]. Our study also shows that there was no significant difference be-

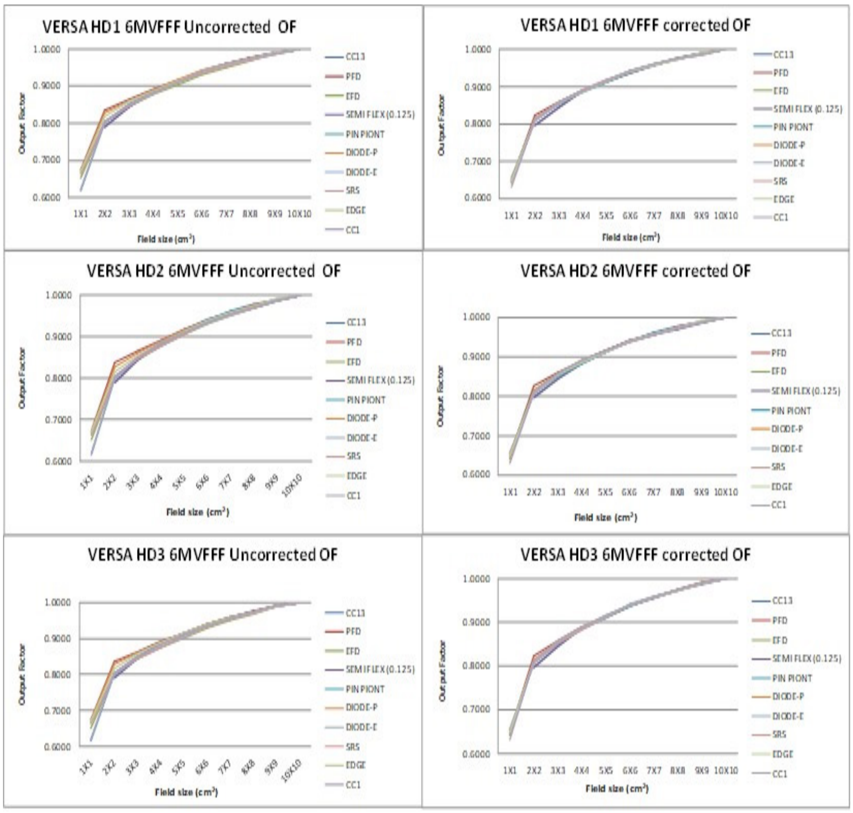

Figure 4. The uncorrected and corrected output factors (OF) for the 6 MV flattening filter free (FFF) photon beam

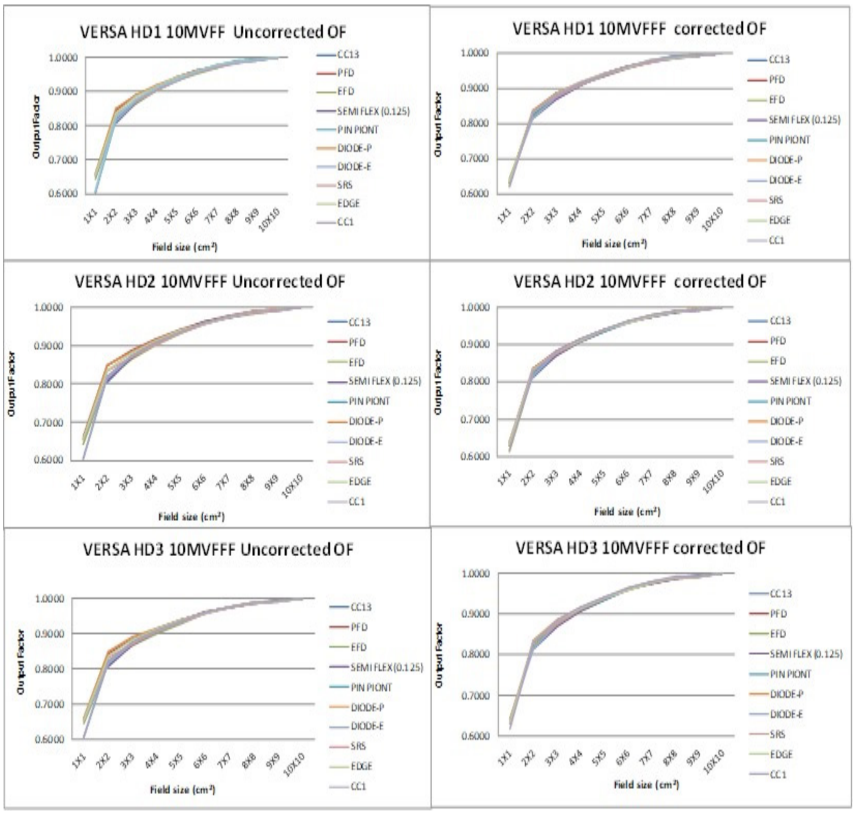

Figure 5. The uncorrected and corrected output factors (OF) for the 10 MV flattening filter free (FFF) photon beam

Table 3. Relative standard deviation of corrected and uncorrected output factors (OF) for 6 MV flattening filter (FF) photon beam

Field size	RSD (%)											
	VERSA HD1			VERSA HD2			VERSA HD3			INFINITY		
	Uncorrected	Corrected	Difference	Uncorrected	Corrected	Difference	Uncorrected	Corrected	Difference	Uncorrected	Corrected	Difference
1 × 1	3.47	1.26	2.21	3.43	1.22	2.22	3.41	1.29	2.12	3.43	1.30	2.14
2 × 2	1.84	0.95	0.89	1.87	0.96	0.91	1.74	0.81	0.93	1.78	0.81	0.97
3 × 3	0.97	0.59	0.39	1.12	0.70	0.42	0.89	0.59	0.30	0.89	0.48	0.41
4 × 4	0.57	0.22	0.34	0.60	0.35	0.25	0.56	0.23	0.32	0.62	0.25	0.37
5 × 5	0.43	0.20	0.24	0.57	0.21	0.35	0.51	0.24	0.27	0.51	0.26	0.24
6 × 6	0.34	0.18	0.16	0.39	0.28	0.11	0.38	0.18	0.20	0.33	0.12	0.20
7 × 7	0.16	0.22	–0.06	0.26	0.26	0.00	0.38	0.24	0.14	0.23	0.16	0.07
8 × 8	0.17	0.18	–0.01	0.18	0.20	–0.02	0.33	0.17	0.16	0.33	0.23	0.10
9 × 9	0.14	0.14	0.00	0.27	0.27	0.00	0.16	0.16	0.00	0.12	0.12	0.00
10 × 10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4. Relative standard deviation of corrected and uncorrected output factors (OF) for 10 MV flattening filter (FF) photon beam

Field size	RSD (%)											
	VERSA HD1			VERSA HD2			VERSA HD3			INFINITY		
	Uncorrected	Corrected	Difference	Uncorrected	Corrected	Difference	Uncorrected	Corrected	Difference	Uncorrected	Corrected	Difference
1 × 1	3.57	1.21	2.36	3.54	1.26	2.28	3.54	1.19	2.35	3.44	1.17	2.27
2 × 2	1.78	0.93	0.85	1.70	0.84	0.86	1.65	0.85	0.81	1.59	0.82	0.78
3 × 3	0.76	0.57	0.20	0.89	0.72	0.17	0.70	0.53	0.17	0.81	0.61	0.19
4 × 4	0.43	0.12	0.31	0.52	0.44	0.09	0.49	0.30	0.19	0.57	0.40	0.17
5 × 5	0.34	0.36	-0.03	0.33	0.37	-0.05	0.37	0.26	0.11	0.37	0.23	0.14
6 × 6	0.28	0.30	-0.02	0.33	0.33	0.00	0.25	0.20	0.06	0.34	0.22	0.11
7 × 7	0.26	0.30	-0.05	0.41	0.42	-0.01	0.23	0.21	0.03	0.30	0.20	0.10
8 × 8	0.28	0.34	-0.06	0.26	0.30	-0.04	0.24	0.16	0.07	0.16	0.14	0.02
9 × 9	0.19	0.19	0.00	0.27	0.27	0.00	0.15	0.15	0.00	0.07	0.07	0.00
10 × 10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Relative standard deviation of corrected and uncorrected output factors (OF) for 6 MV flattening filter free (FFF) photon beam

Field size	RSD (%)								
	VERSA HD1			VERSA HD2			VERSA HD3		
	Uncorrected	Corrected	Difference	Uncorrected	Corrected	Difference	Uncorrected	Corrected	Difference
1 × 1	3.50	1.21	2.29	3.54	1.35	2.19	3.57	1.23	2.34
2 × 2	1.86	1.01	0.85	1.90	1.05	0.85	1.88	0.99	0.89
3 × 3	0.85	0.61	0.24	0.87	0.65	0.22	0.87	0.55	0.32
4 × 4	0.54	0.22	0.32	0.58	0.34	0.25	0.74	0.23	0.52
5 × 5	0.43	0.25	0.18	0.48	0.18	0.29	0.56	0.22	0.34
6 × 6	0.36	0.23	0.13	0.37	0.13	0.24	0.37	0.15	0.22
7 × 7	0.34	0.18	0.16	0.39	0.20	0.19	0.29	0.15	0.14
8 × 8	0.27	0.10	0.17	0.36	0.23	0.12	0.23	0.12	0.11
9 × 9	0.19	0.19	0.00	0.20	0.20	0.00	0.12	0.12	0.00
10 × 10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 6. Relative standard deviation of corrected and uncorrected output factors (OF) for 10 MV flattening filter free (FFF) photon beam

Field size	RSD(%)								
	VERSA HD1			VERSA HD2			VERSA HD3		
	Uncorrected	Corrected	Difference	Uncorrected	Corrected	Difference	Uncorrected	Corrected	Difference
1 × 1	3.56	1.20	2.35	3.65	1.58	2.07	3.52	1.16	2.36
2 × 2	1.81	1.04	0.77	1.92	1.10	0.82	1.79	1.02	0.77
3 × 3	1.06	0.73	0.33	0.82	0.51	0.32	0.95	0.65	0.30
4 × 4	0.59	0.41	0.18	0.54	0.31	0.23	0.53	0.33	0.19
5 × 5	0.45	0.31	0.14	0.36	0.22	0.14	0.39	0.26	0.14
6 × 6	0.32	0.22	0.10	0.24	0.19	0.05	0.17	0.19	–0.03
7 × 7	0.33	0.24	0.09	0.17	0.20	–0.03	0.08	0.20	–0.12
8 × 8	0.23	0.24	–0.01	0.19	0.13	0.06	0.19	0.19	0.00
9 × 9	0.13	0.13	0.00	0.19	0.19	0.00	0.15	0.15	0.00
10 × 10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

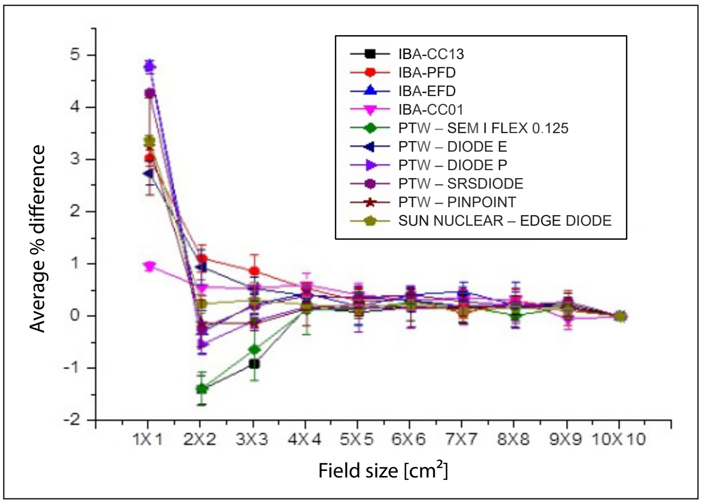

Figure 6. Comparison of measured and treatment planning system (TPS) generated output factors (OF) for 6 MV flattening filter (FF) photon beam

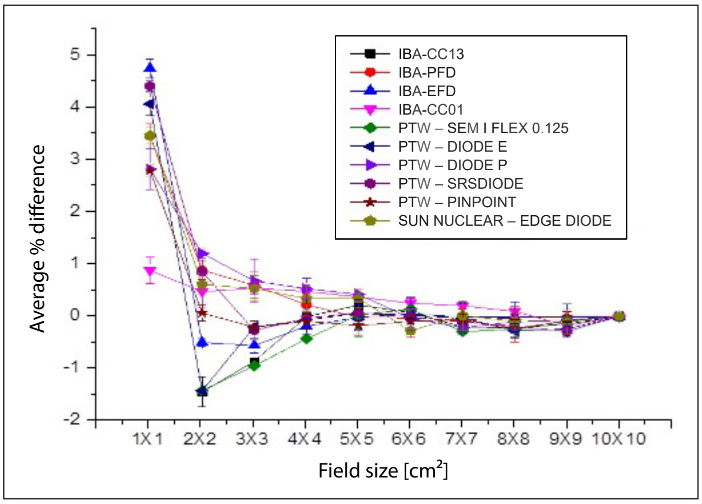

Figure 7. Comparison of measured and treatment planning system (TPS) generated output factors (OF) for 10 MV flattening filter (FF) photon beam

tween the geometric and calculated equivalent square field (S_{clin}) sizes for Agility collimator.

Clare et al., 2019, found that the RSD value for corrected OF was reduced for all types of detector compared to the uncorrected OF. The percentage difference between the corrected and uncorrected OF values decreased with increasing field size [19]. Our results also showed that the maximum RSD variations among all detectors for a field size of 1 × 1 cm^2 were 3.57, 1.23, and 2.34% for uncorrected, corrected and maximum difference, respectively. For a field size ≥ 2 × 2 cm^2, the RSD difference was less than 1% for all energies and the RSD values further decreased with increasing field size.

The corrected OFs obtained in this study were in good agreement with the literature values, and the TRS 483-detector-specific OCF helped to reduce the uncertainty in small-field measurements, mainly due to the loss of charge particle equilibrium, source occlusion, detector material, and chamber volume.

Wolfgang et al., 2018, show the treatment unit measured and TPS OF data in multinational audit. For the 2 × 2 cm^2 field size the mean values of the ratio of calculated and reference OFs were significantly different from unity, for Varian linacs — Eclipse TPS the value was 1.030 ± 0.003 (p-value < 0.01), for Elekta linacs — Monaco the val-

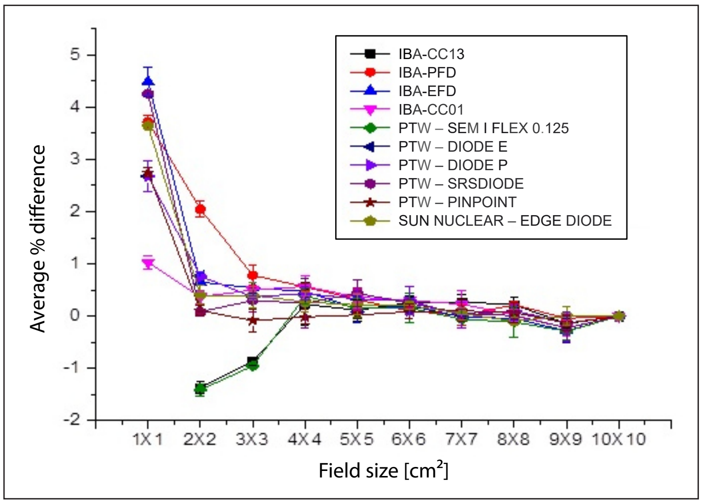

Figure 8. Comparison of measured and treatment planning system (TPS) generated output factors (OF) for 6 MV flattening filter free (FFF) photon beam

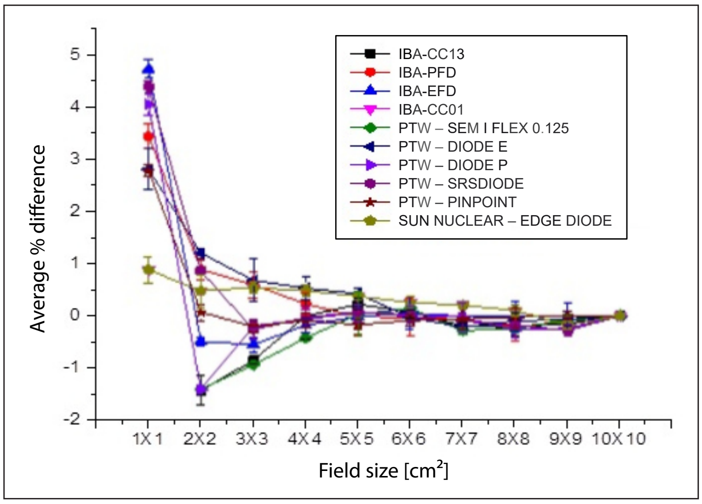

Figure 9. Comparison of measured and treatment planning system (TPS) generated output factors (OF) for 10 MV flattening filter free (FFF) photon beam

ue was 1.013 ± 0.003 (p-value < 0.01) and for Siemens linacs – Oncentra the value was 1.033 ± 0.006 (p-value = 0.016). The difference increased with decrease in field size. In some institutions the difference was more than the action limit [24].

The corrected OF was compared with the TPS-calculated OF, and the IBA EFD unshielded diode showed the maximum variations of 4.81 ± 0.10, 4.49 ± 0.28, 4.65 ± 0.03, and 4.73 ± 0.18% for 6 MV FF, 6 MV FFF, 10 MV FF, and 10 MV FFF photon beams, respectively. In contrast, the IBA CC01 chamber showed low variations of 0.96 ± 0.09, 1.03 ± 0.14, 0.91 ± 0.05 and 0.88 ± 0.25% for 6 MV FF, 6 MV FFF, 10 MV FF, and 10 MV FFF photon beams, respectively. The TPS was commissioned using an IBA CC01 chamber. However, the TRS 483-recommended corrected factor was not used during TPS commissioning.

Conclusion

The measured OFs for four beam-matched linear accelerators were corrected using the detector-specific correction factors provided in the IAEA TRS 483 protocol. The corrections were applied to all the detectors used in this study. However, for the IBA CC13 and PTW SemiFlex 31010 chambers the correction factors were applied for the field size ≥ 2 × 2 cm². The corrected OFs showed less significant variations and were more consistent than the uncorrected OFs for field sizes ≥ 2 × 2 cm². Moreover, for a small-field size of 1 × 1 cm² the corrected OF showed a similar response. The measured OF variations among the beam-matched linacs were consistent for all detectors.

The corrected OF for the CC01 chamber showed a maximum variation of 1.03% compared to the TPS-calculated OF. This could have been because the TPS OF was initially commissioned without employing the IAEA TRS 483-recommended correction factor. These findings suggest that it is necessary to implement the corrected OF for small fields in a TPS. Special care must be taken to incorporate the corrected small-field OF in TPS.

Conflict of interest

None declared.

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