Original Article

Evaluation of International Atomic Energy Agency Technical Report Series-483 Detector-specific Output Correction Factor for Various Collimator Systems

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Abstract

Aim: In this study, a 6MV flattening filter (FF) and 6MV FF Free (FFF) photon beam small-field output factors (OF) were measured with various collimators using different detectors. The corrected OFs were compared with the treatment planning system (TPS) calculated OFs. **Materials and Methods:** OF measurements were performed with four different types of collimators: Varian Millennium multi-leaf collimator (MLC), Elekta Agility MLC, Apex micro-MLC (mMLC) and a stereotactic cone. Ten detectors (four ionization chambers and six diodes) were used to perform the OF measurements at a depth of 10 cm with a source-to-surface distance of 90 cm. The corrected OF was calculated from the measurements. The corrected OFs were compared with existing TPS-generated OFs. **Results:** The use of detector-specific output correction factor (OCF) in the PTW diode P detector reduced the OF uncertainty by <4.1% for 1 cm × 1 cm S_{clin}. The corrected OF was compared with TPS calculated OF; the maximum variation with the IBA CC01 chamber was 3.75%, 3.72%, 1.16%, and 0.90% for 5 mm stereotactic cone, 0.49 cm × 0.49 cm Apex mMLC, 1 cm × 1 cm Agility MLC, and 1 cm × 1 cm Millennium MLC, respectively. **Conclusion:** The technical report series-483 protocol recommends that detector-specific OCF should be used to calculate the corrected OF from the measured OF. The implementation of OCF in the TPS commissioning will reduce the small-field OF variation by <3% for any type of detector.

Keywords: Output factor, small-field dosimetry, stereotactic cone, technical report series - 483, treatment planning systems

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Introduction

The aim of radiotherapy is to deliver a maximum dose to the tumor and a minimum dose to the surrounding normal tissues, which may be comfortably achieved using advanced techniques such as intensity- modulated radiotherapy (IMRT), stereotactic radiosurgery (SRS), stereotactic radiotherapy (SRT), and stereotactic body radiotherapy (SBRT).[1] To achieve these goals, multi-leaf collimator (MLC), micro-MLC (mMLC), and stereotactic cones are used to create small segments.[2,3] The small segments dosimetry should be very accurate in the treatment planning system (TPS) to achieve the expected clinical outcomes. Small-segment field dosimetry is more complicated than that of other conventional fields.[2-7] The reasons are lack of lateral charge particle equilibrium (LCPE), partial occlusion of the primary radiation source, and measurement detector size. The first two are related to the beam energy and collimation, and the third is related to the detector.[2] Small-field measuring detectors have very small volumes, and high spatial resolution and should satisfy the ideal characteristics of the detector.[8,9] There is no ideal detector available to measure small fields owing to the engineering of detector design, tolerance limits, and perturbation factors.[2-4] The LCPE, volume average, and nontissue equivalence of detector materials prompted the need for detector-specific output correction factors (OCFs). Detector-specific OCFs have been obtained for various detectors available in the literature,

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which were determined based on any one of the following methods: (i) use of an empirical comparison between the field and reference detector signal ratios to generate the correction.[7,10-13] (ii) Use of a numerical simulation model, such as Monte Carlo, to generate the correction factor.[14] (iii) Use of a semi-empirical approach. Most of the research works based on this last method compare the measurements and simulations to generate the correction factor.[15-19] The American Association of Physicists in Medicine and the International Atomic Energy Agency (IAEA) published the Technical Report Series-483 (TRS-483) protocol for small-field dosimetry.[2] The protocol contains a set of detector-specific OCF for detectors manufactured by different vendors, such as M/s. PTW, M/s. IBA, M/s. Sun Nuclear, and M/s. Standard Imaging. Smith *et al*. evaluated the TRS483 protocol-recommended OFs for 6 MV FF photon beam using nine detectors in the Elekta SRS cone and MLC.[20] However, in the literature, OF data are not available for Varian Millennium MLC and Elekta Apex mMLC with 6MVFF and 6MV FFF photon beams. Hence, in this study, the small-field corrected OFs of 6MVFF and 6MVFFF photons were measured and compared for various collimators with different detectors. The corrected OFs were compared with TPS-calculated OFs.

Materials and Methods

The OF measurements were performed using four different types of collimators. These collimators are Varian Millennium MLC, Elekta Agility MLC, Elekta Apex mMLC, and Elekta stereotactic cones.

Millennium multi-leaf collimator

A low-energy DBX™ linear accelerator (Varian Medical Systems, Palo Alto, CA, USA) with a single-photon beam energy of 6MVFF was used for OF measurement. The machine has a 120-leaf Millennium MLC as a tertiary collimator. The leaf pairs open to a maximum field size of 40 cm × 40 cm at the isocenter. The leaf width is 5 mm in the central 20 cm of the field and 1 cm at the periphery of the collimator. The measurement was performed for an MLC field setting of 1 cm × 1 cm–10 cm × 10 cm and the jaws were placed 5 mm from the field edge of the MLC.[21-23]

Agility multi-leaf collimator

The OF measurement was carried out in 6MV (FF and FFF) photon beams of the VersaHD™ linear accelerator (Elekta AB, Stockholm, Sweden) having an Agility MLC head with 80 pairs of leaves. All the leaves have a width of 5 mm at the isocentric plane opening up to 40 cm x 40 cm. The OF measurements were carried out for field sizes ranging from 1 cm × 1 cm to 10 cm × 10 cm.

Apex micro-multi-leaf collimator and stereotactic cone

The OF measurements were also performed for Apex mMLC and stereotactic cones. The Apex mMLC and stereotactic cones are add-on collimators for Versa HD™ linear accelerator. The Apex mMLC has field sizes ranging from 0.49 cm × 0.49 cm to 12 cm × 14 cm and leaf width of 2.5 mm. The available stereotactic cone diameters are 5, 7.5, 10, 12.5, and 15 mm. The OF measurements were performed with 6MVFF and 6MVFFF photon beams, during which the jaw setting was 2 cm × 2 cm for the 5 mm cone, and for all other cones it was 3 cm × 3 cm. For the measurements with the Apex mMLC, the jaws were positioned at 5 mm away from the periphery of the mMLC.[22-24]

Detectors

Ten different types of detectors (four ionization chambers and six diode detectors) were used for the OF measurements. The physical characteristics of these detectors are listed in Table 1. PTW Unidos and IBA Dose 1 electrometers were used for the measurements. The bias voltage for the ionization chamber was +300V and that for the diode was 0V. For all measurements, the ion chambers and edge diodes were positioned perpendicular to the central axis (CAX) of the beam, and all other diodes were positioned parallel to the CAX of the beam. The measurement setup used in this study is shown in Figure 1.

Measurements

OF measurements were performed using IBA Dosimetry (Blue phantom²) with my QA 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 CAX position was verified before the measurement with each detector. The measurements were performed at an source-to-surface distance (SSD) of 90 cm and a depth of 10 cm, and the detector was positioned at the isocenter. The experimental setup for the OF measurements is shown in Figure 2. The OF was measured for field sizes ranging from 1 cm × 1 cm to 10 cm × 10 cm using ten different types of detectors, with a 10 cm × 10 cm field size as the reference size for the Millennium and Agility MLC. The OF was also measured for stereotactic cones and Apex mMLC field sizes. The reference field size for the Apex mMLC was 9.84 cm × 9.84 cm and the stereotactic cone was 15 mm diameter. Among ten detectors used in this study, the IBACC13 and PTW semiflex31010 ion chambers were used only for equivalent square field -(S_{clin}) ≥1.5 cm² for all collimators.

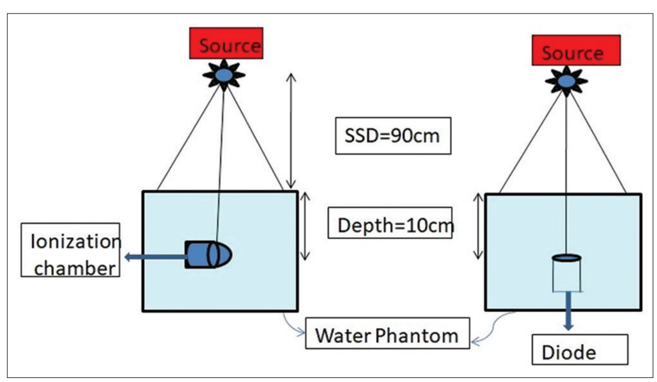

Figure 1: Detectors position in the central axis of the beam

Table 1: Physical characteristics of the detectors

Label	Type	Active volume dimensions	Detector material	Effective atomic number (z_{eff})
IBA CC13	Air filled-cylindrical ionization chamber	Diameter - 6 mm Height - 5.8 mm Volume - 0.13 mm^3	Air	7.6
IBA CC01	Air filled-cylindrical ionization chamber	Diameter - 2 mm Height - 3.6 mm Volume - 0.1 mm^3	Air	7.6
IBA PFD 3G	Shielded diode	Disk diameter - 2 mm Thick - 0.06 mm Volume - 0.19 mm^3	Silicon	14
IBA EFD 3G	Unshielded diode	Disk diameter - 2 mm Thick - 0.06 mm Volume - 0.19 mm^3	Silicon	14
PTW pinpoint 31014	Air filled-cylindrical ionization chamber	Diameter - 2 mm Height - 5 mm Volume - 15 mm^3	Air	7.6
PTW semiflex 31010	Air filled-cylindrical ionization chamber	Diameter - 5.5 mm Height - 6.5 mm Volume - 125 mm^3	Air	7.6
PTW diode P 60016	Shielded diode	Disk diameter - 1.13 mm Thick - 2.5 µm Volume - 0.0025 mm^3	Silicon	14
PTW diode E 60017	Unshielded diode	Disk diameter - 1.13 mm Thick - 30 µm Volume - 0.03 mm^3	Silicon	14
PTW diode SRS 60018	Unshielded diode	Disk diameter - 1.13 mm Thick - 250 µm Volume - 0.3 mm^3	Silicon	14
Sun nuclear edge diode	Shielded diode	Square - 0.8 mm × 0.8 mm Thick - 30 µm Volume - 0.019 mm^3	Silicon	14

3G: Three dimensional

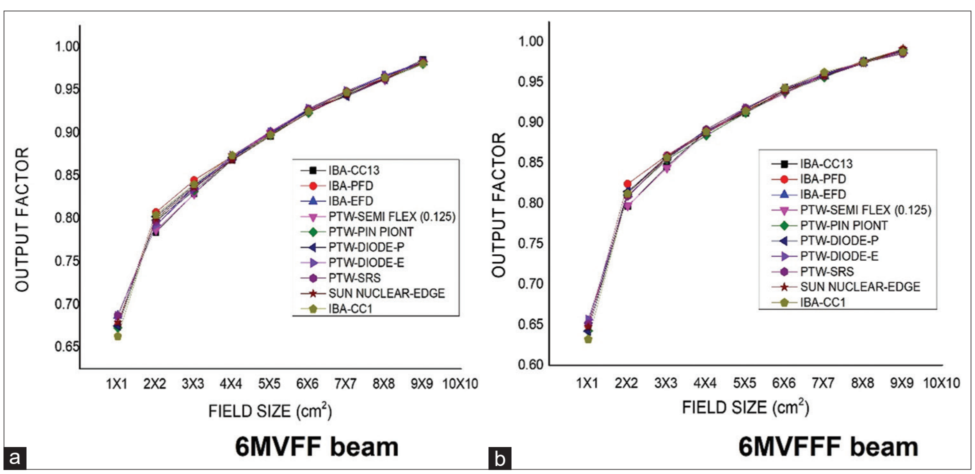

Figure 2: Corrected output factor for Agility multi-leaf collimator (a) 6MV flattening filter beam (b) 6MVFF free beam. OF: Output factor, 6MVFF: 6MV flattening filter, 6MVFFF: 6MV flattening filter free

The mechanical leaf position accuracy was tested and the standard deviation was accounted for to ensure the MLC position for all field sizes. The pre- and postirradiation leakage was recorded before each measurement. The measurement was repeated three times with 100 monitor units (MU). The meter reading was corrected for the influence quantities as recommended by TRS 483 protocol.[2] The output consistency and beam quality ($TPR_{20,10}$) were monitored daily before the measurements. A detector-specific OCF was applied to each detector, and the corrected OF was calculated.

$$\text{corrected OF} = \frac{\text{Detector meter reading for given field size}}{\text{Detector meter reading for reference field size}} \times \text{©Detector specific OCF}^{*} \quad (1)$$

* Detector – specific OCF provided in TRS 483 protocol[2]

The relative standard deviation (RSD) was also calculated for corrected OF values of the various detectors and collimators.

$$\text{RSD} = \frac{\text{Standard deviation}}{\text{Mean}} \times 100 \quad (2)$$

Comparison of corrected and treatment planning system calculated output factors

The treatment planning systems used in this study were Eclipse 13.7 (Varian Medical Systems, Palo Alto, CA) and Monaco5.51.10 (Elekta AB, Stockholm, Sweden). Eclipse beam data were commissioned for the AAA algorithm, and Monaco beam data were commissioned for the Monte Carlo, Pencil Beam, and collapsed cone convolution algorithms. At the time of the TPS commissioning, the daisy chain approach was not used for the small field OF measurement. In the TPS, the MU was calculated for the 10 Gy dose at 10 cm depth in a water phantom using 90 cm SSD for all the field sizes and cones used in this study. The dose/MU was calculated for each field, which was normalized to the reference field.[21] This TPS calculated OF was compared with the corrected OFs from the measurements.

Results

Output factor

Figure 2 shows the measured corrected OF for the Agility MLC for the 6MVFF and 6MVFFF photon beams with various detectors. For the 6MVFF photon beam, the maximum and minimum corrected OF were 0.6874 (PTW SRS Diode) and 0.6631 (IBA CC01), respectively, for a field size of 1 cm × 1 cm. For the 6MVFFF photon beam, the maximum and minimum corrected OF were 0.6565 (IBA Diode E) and 0.6322 (IBA CC01), respectively, for a field size of 1 cm × 1 cm. Figure 3 shows the measured corrected OFs for the Millennium MLC with a 6MVFF photon beam for various detectors. The maximum and minimum corrected OFs were 0.6806 (IBA EFD) and 0.6569 (PTW Pinpoint), respectively, for a field size of 1 cm × 1 cm. Figure 4 shows the measured corrected OFs for the Apex mMLC for the 6MVFF and 6MVFFF photon beams with various detectors. For the 6MVFF photon beam, the maximum and minimum corrected OF values were 0.7672 (IBA EFD) and 0.7259 (IBA CC01) for 0.98 cm × 0.98 cm field size. For the 6MVFFF beam, the maximum and minimum corrected OFs were 0.7259 (IBA EFD) and 0.6966 (IBA CC01) for 0.98 cm × 0.98 cm field size. Figure 5 shows the measured corrected OF for the stereotactic cone for the 6MVFF and 6MVFFF photon beams with various detectors. For the 6MVFF photon beam, the maximum and minimum corrected OF values were 0.9464 (PTW Diode E) and 0.9345 (IBA CC01), respectively, for a cone diameter of 10 mm.

The RSD of the OFs was calculated for all collimator systems using the corrected OF values, and the results are shown in Tables 2-4. The RSD values increased with a decrease in the field size except for the stereotactic cone. For Agility MLC with 6MVFF and 6MVFFF photon beams, the maximum RSD values were 1.12% and 1.10%, respectively. For Millennium MLC with 6MVFF photon beams, the maximum RSD value was 1.15%. For Apex mMLC with 6MVFF and 6MVFFF photon beams, the maximum RSD values were 1.81% and 1.72%, respectively. For stereotactic cones with 6MVFF and 6MVFFF photon beams, the maximum RSD values were 0.80% and 0.58%, respectively.

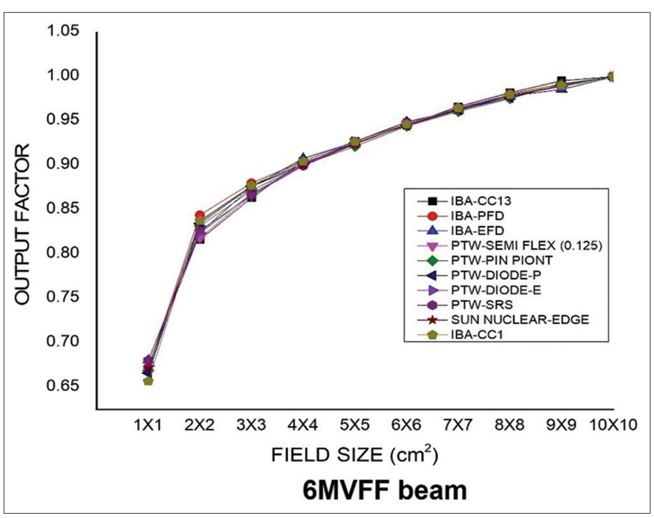

Figure 3: Corrected output factor for Millennium multi-leaf collimator with 6MV flattening filter beam. OF: Output Factor, 6MVFF: 6MV flattening filter

Table 2: Relative standard deviation for corrected OF in Agility and millennium multi-leaf collimator

Field size (cm^2)	RSD (%)		
	Agility MLC		Millennium MLC (6MVFF)
	6MVFF	6MVFFF	
1×1	1.12	1.10	1.15
2×2	0.95	1.01	1.10
3×3	0.59	0.61	0.66
4×4	0.22	0.22	0.29
5×5	0.20	0.25	0.20
6×6	0.18	0.23	0.17
7×7	0.22	0.18	0.17
8×8	0.18	0.10	0.20
9×9	0.14	0.19	0.25
10×10	0.00	0.00	0.00

RSD: Relative standard deviation, MLC: Multi-leaf collimator, 6MVFFF: 6MV flattening filter free, 6MVFF: 6MV flattening filter

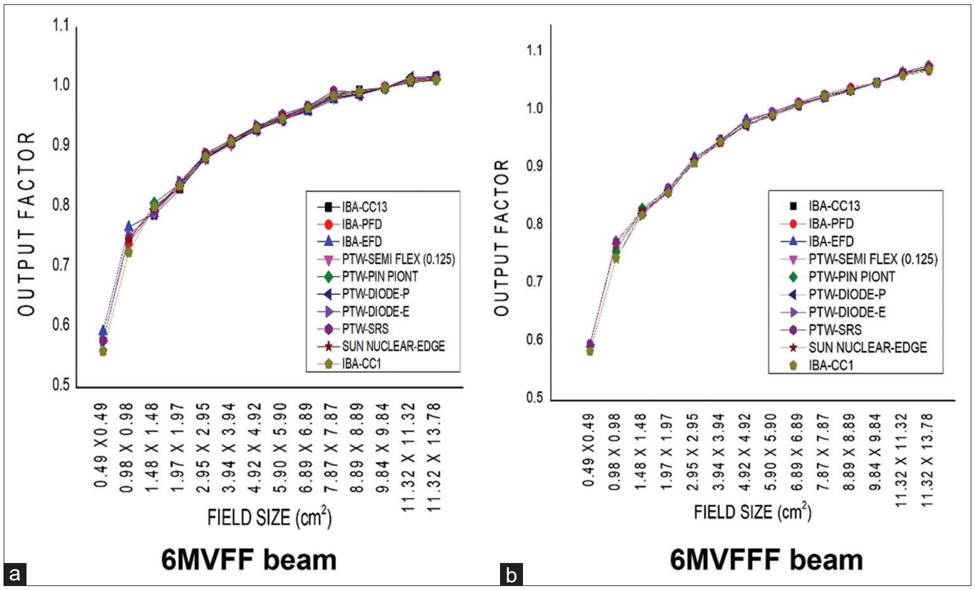

Figure 4: Corrected output factor for Apex micro multi-leaf collimator (a) 6MV flattening filter beam (b) 6MVFF free beam. OF: Output factor, 6MVFF: 6MV flattening filter, 6MVFFF: 6MV flattening filter free

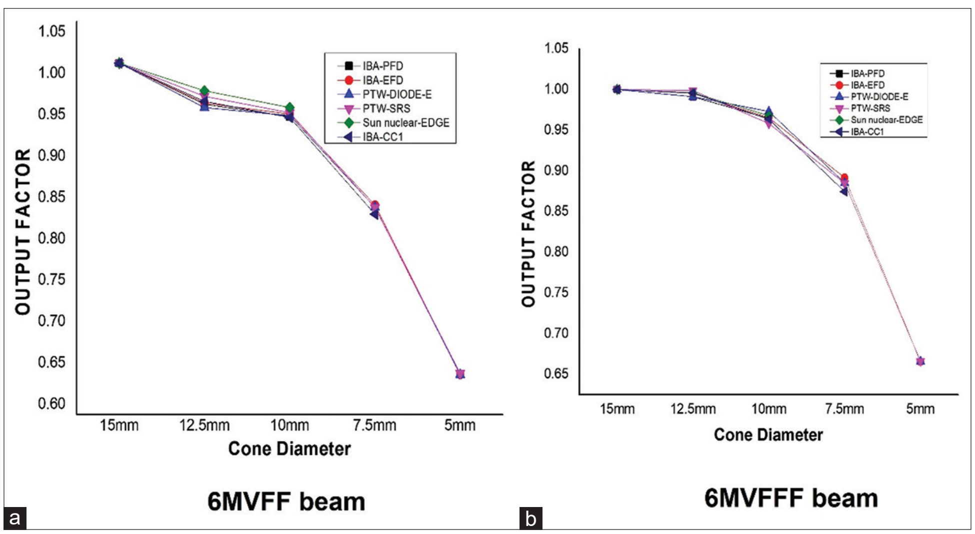

Figure 5: Corrected output factor for stereotactic cone (a) 6MV flattening filter beam (b) 6MVFF free beam. OF: Output factor, 6MVFF: 6MV flattening filter, 6MVFFF: 6MVFF free

Comparison of corrected and treatmentplanning system calculated output factor

The variation between the TPS generated and corrected OF is shown in Figures 6-9. For Agility MLC with a 6MVFF photon beam, the maximum variation was 4.72% (IBA EFD) and with a 6MVFFF Photon beam, with a maximum variation of 5.05% (PTW Diode E). For Millennium MLC with a 6MVFF photon beam, maximum variation was 4.55% (IBA EFD). For Apex mMLC with a 6MVFF photon beam, the maximum variation was 6.37% (PTW SRS Diode) and with a 6MVFFF photon beam, the maximum variation was 6.21% (PTW SRS Diode). For the stereotactic cone with a 6MVFF Photon beam, the maximum variation was 6.59% (PTW SRS Diode), and with a 6MVFFF Photon beam, the maximum variation was 6.36% (PTW SRS Diode).

Discussion

Garnier *et al*. compared the unshielded and shield diodes measured OF with the Monte Carlo study, and their results show over responses of 3.3% and 5.2% for unshielded and shield diodes with ≥10 mm cones.[25] In our studies, the shielded diode showed an over-response of 1.7% compared with the unshielded diode for S_{clin} ≥1 cm × 1 cm. In addition, the diode OFs show more response than the ionization chamber, which may be due to the higher silicon density in the diode and the greater volume-averaging effect in the ionization chamber. This has been reported in the literature by several authors.[10,11,24-29] In our study, three shielded diodes were used to measure the OFs (PTW Diode P, IBA PFD, and Edge diode); among these, the Sun nuclear Edge diode shows a less response of

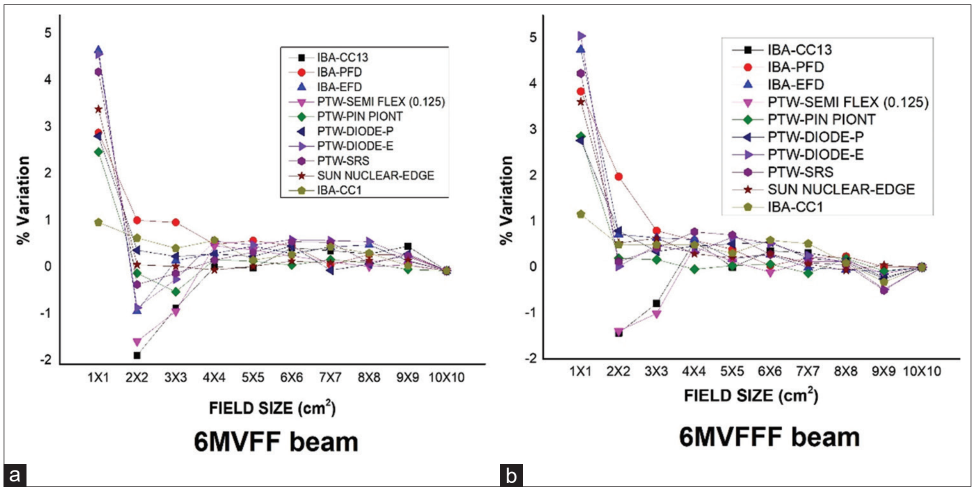

Figure 6: Comparison of treatment planning system generated and corrected output factor for Agility multi-leaf collimator (a) 6MV flattening filter beam (b) 6MVFF free beam. OF: Output factor, 6MVFF: 6MV flattening filter, 6MVFFF: 6MV flattening filter free

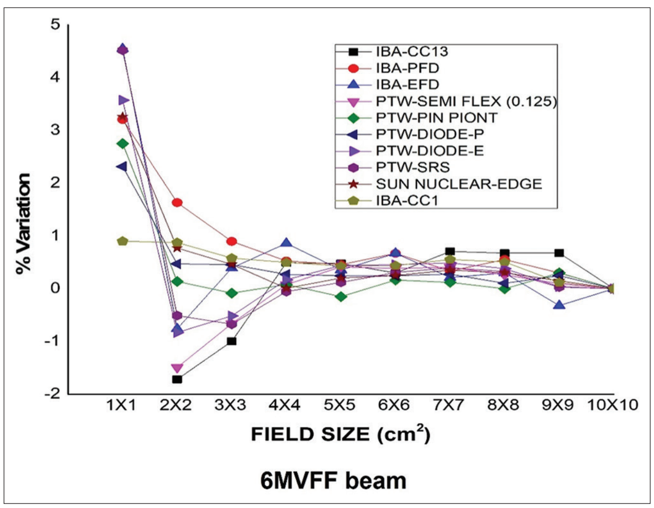

Figure 7: Comparison of treatment planning system generated and corrected output factor for millennium multi-leaf collimator with 6MV flattening filter beam. 6MVFF: 6MV flattening filter

0.4% compared to the other two detectors. This could be due to less scatter contribution from the shielding for small-field OF measurements. Mamesa *et al*. also reported that the sun nuclear Edge diode shows a lesser response compared to the IBA PFD diode for small-field OF measurements.[30]

Shukaili *et al*. showed that for the SFD detector, the detector-specific OCF reduces the uncertainty by 3.7% for the 5 mm cone.[9] The detector-specific OCFs were also used in our study to reduce the uncertainty of the detectors in the small-field OF measurements. The PTW diode *P* detector shows the maximum reduction in the uncertainty, which is <4.1% for 1 cm × 1 cm S_{clin}. Smith *et al*. evaluated the TRS-483 detector-specific OCF for small-field measurements and found the RSD values for nine detectors using corrected OF values. The maximum RSD values for the corrected OF were 1.2% and 0.8% for the 5 mm cone and Agility MLC (1 cm × 1 cm field size) for the 6MVFF-photon beam.[20] Our results show that the maximum RSD values for the corrected OF were 0.8%, 1.81%, 1.12%, and 1.15% for 7.5 mm stereotactic cone, 0.49 cm × 0.49 cm Apex MLC, 1 cm × 1 cm Agility

Table 3: Relative standard deviation for corrected OF in Apex micro multi-leaf collimator

Field size (cm^2)	RSD (%)	
	6MVFF	6MVFFF
0.49×0.49	1.81	1.72
0.98×0.98	1.25	1.35
1.48×1.48	0.76	0.50
1.97×1.97	0.45	0.38
2.95×2.95	0.35	0.37
3.94×3.94	0.30	0.25
4.92×4.92	0.27	0.43
5.90×5.90	0.31	0.27
6.89×6.89	0.27	0.23
7.87×7.87	0.42	0.25
8.89×8.89	0.26	0.20
9.84×9.84	0.00	0.00
11.32×11.32	0.24	0.23
11.32×13.78	0.20	0.31

6MVFFF: 6MV flattening filter free, 6MVFF: 6MV flattening filter, RSD: Relative standard deviation

Table 4: Relative standard deviation for corrected output factor in stereotactic cone

Cone size diameter (mm)	RSD (%)	
	6MVFF	6MVFFF
5.0	0.13	0.07
7.5	0.80	0.58
10.0	0.51	0.46
12.5	0.36	0.30
15.0	0.00	0.00

6MVFFF: 6MV flattening filter free, 6MVFF: 6MV flattening filter, RSD: Relative standard deviation

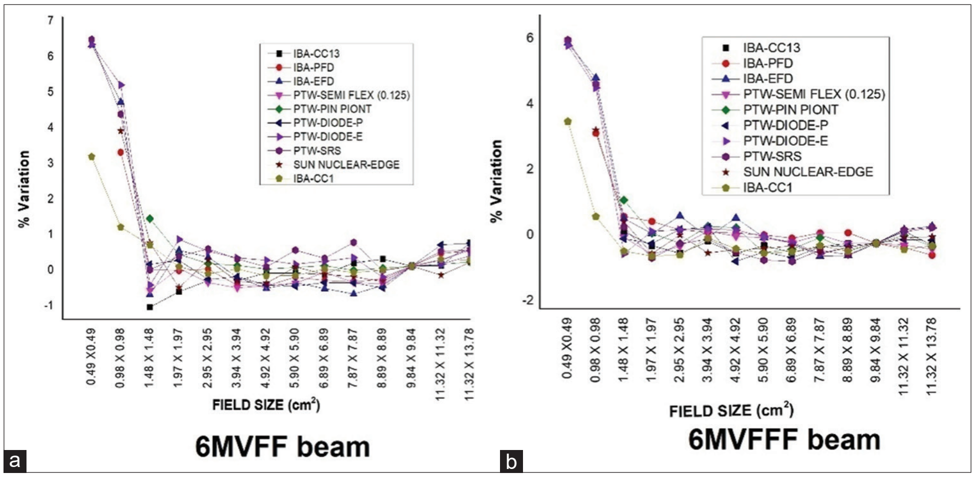

Figure 8: Comparison of treatment planning system generated and corrected output factor for Apex micro multi-leaf collimator (a) 6MV flattening filter beam (b) 6MVFF free beam. 6MVFF: 6MV flattening filter, 6MVFFF: 6MVFF free

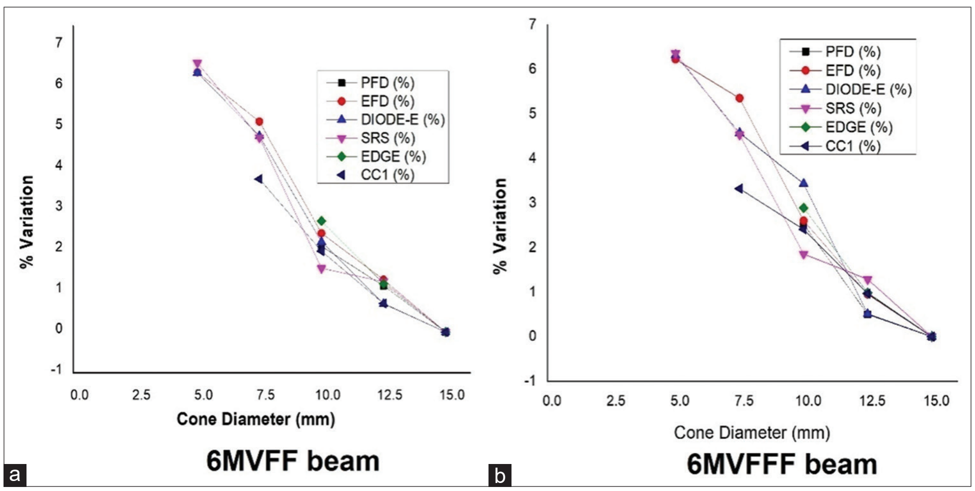

Figure 9: Comparison of treatment planning system generated and corrected output factor for stereotactic cone (a) 6MV flattening filter beam (b) 6MV flattening filter free beam. 6MVFF: 6MV flattening filter, 6MVFFF: 6MVFF free

MLC, and 1 cm × 1 cm Millennium MLC, respectively, for 6MVFF-photon beam.

Lechner *et al*. conducted an audit of the multinational and national runs by setting an action limit of ± 3% for a field size <2 cm × 2 cm for the mean ratio of TPS calculated and measured OF. In the multinational run, almost 30% of institutional data points were beyond the limit, and in the national run, almost 35% of institutional data points were beyond the action limit.[21] Similarly, Followill *et al*. conducted a single institutional study and showed a 7.9% of standard deviation for 2 cm × 2 cm field size.[31] In our study, the corrected OF was compared to the TPS-calculated OF. For all collimators, as the field size decreased, the variation between the corrected and TPS-calculated OF increased for both the 6MVFF and 6MVFFF photon beams. The maximum variation was observed for the minimum field size in all the collimators. The maximum variation among the ten detectors was 6.35% ± 0.09% and 6.21% ± 0.09% for 6MVFF and 6MVFFF photon beams, respectively, for the unshielded diode. At the time of TPS commissioning, the TRS-483 recommendation was not available to obtain detector-specific OCF; hence, it was not incorporated for the small fields in the TPS. Hence, the comparison shows more deviation for unshielded diodes. The existing TPS algorithm was commissioned based on IBA CC01 chamber data. The maximum variation was noted with the IBA CC01 chamber, which was 3.7%, 3.72%, 1.16%, and 0.90% for 5 mm stereotactic cone, 0.49 cm × 0.49 cm Apex MLC, 1 cm × 1 cm Agility MLC, and 1 cm × 1 cm Millennium MLC, respectively.

Conclusion

In this study, the OF was measured for four different collimator systems with 6MVFF and 6MVFFF photon beams using various detectors (ionization chamber and diode detectors). The TRS 483 protocol, given the detector-specific OCF, was used to calculate the corrected OF. The RSD value was calculated for the all-collimator systems, and a maximum of 1.81% variation was observed among all the detectors.

The corrected OFs for the shielded diode show a maximum variation of 4.1% and the same measured by CC01 chamber shows a maximum variation of 3.75% compared to the TPS-calculated OFs. This could be because the TPS OF was initially commissioned without employing the IAEA TRS 483-recommended OCF for the CC01 chamber. These findings suggest that it is necessary to implement the corrected OFs for a small-field beam configuration in the TPS. The implementation of IAEA TRS 483 given OCF in the TPS commissioning will reduce the small-field OF variation by <3% for any detector.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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