



Relative output factors of different collimation systems in truebeam STx medical linear accelerator

Do Duc Chi¹, Tran Ngoc Toan², Robin Hill^{3,4}, Nguyen Do Kien¹

¹108 Military Central Hospital, Hanoi, Vietnam

²Vietnam Atomic Energy Institute, Hanoi, Vietnam

³Chris O'Brien Lifecare, NSW, Australia

⁴School of Physics, The University of Sydney, NSW Australia

Email: chidd108@gmail.com

Abstract: The IAEA TRS483 and TRS398 Code of Practices (CoP) were used to calculate relative output factors for small photon beams of 6X, 6XFFF energies shaped by High Definition Multileaf Collimator (HDMLC), jaws and cones mounted on TrueBeam STx medical linear accelerator (Varian Medical Systems), respectively. A comparison between these results were made. The results show a large discrepancy in relative output factor curves found among different collimation systems of the same equivalent field sizes and between the CoPs. Therefore, the specific beam modelling in treatment planning system for each type of the collimation system to be used for small fields maybe required for better computational accuracy.

Keywords: TRS483 code of practice, small field dosimetry, relative output factors.

I. INTRODUCTION

Modern radiotherapy techniques such as Intensity-Modulated Radiation Therapy (IMRT), Volumetric Modulated Arc Therapy (VMAT), Stereotactic Radiosurgery (SRS) and Stereotactic Radiation Therapy (SRT) make use of small photon beams in order to deliver complex radiation treatments. However, there are still many physical and technical aspects which need to be considered in order to commission small photon beams safely and efficiently in clinical practice such as: changing in photon fluence spectrum making beam quality changing by field size, lateral disequilibrium of charged particles may leading to wrong estimation of absorbed dose as well as detector size compared to field size [1–4].

Practical issues encountered are: photon beam data for treatment planning system (TPS) are usually collected for jaw-shaped beams while we use these data for computation of Multileaf Collimator (MLC) - shaped beams. Furthermore, HDMLC-shaped beams are constituted from very tiny beamlets, much smaller than smallest collected beam data of field size of $3 \times 3 \text{ cm}^2$ (at isocenter), which may affect the computation accuracy of TPS, especially for small tumors. In Eclipse v.13.6 (Varian Medical Systems), warning message “inaccuracy” was often seen when making treatment plans for tumors less than 3 cm diameter. Radiation oncologists tend to use HDMLC for small tumor radiosurgery because of its small thickness (2.5 mm at isocenter) and convenience.

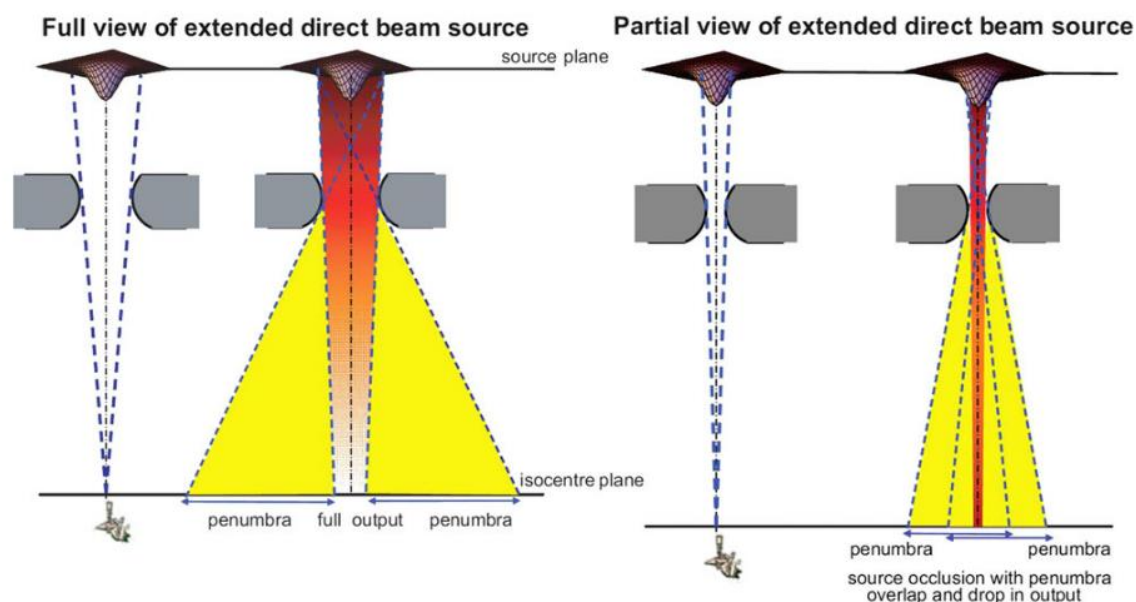


Fig. 1. Occlusion of photon source in the case of narrow collimation. Left: the full, extended source can be “viewed” by an observer on the central axis. Right: only partial view of the source is possible by an observer on the central axis [13]

Conical collimators are dedicated for radiosurgery of small tumors. With cone-shaped beams, field size diameters are of 17.5 mm down to 4 mm cone, but they are previously measured using TRS 398 CoP published by the IAEA [14]. It has been shown that the beam quality of photon beam changes significantly due to these

very small field collimations [2], [5–9]. In this study, we made a comparison of relative output factors of different collimation systems (jaws, HDMLC and cones) for further estimation of the computational accuracy of TrueBeamSTx TPS using newly published TRS 483 CoP by the IAEA [2].

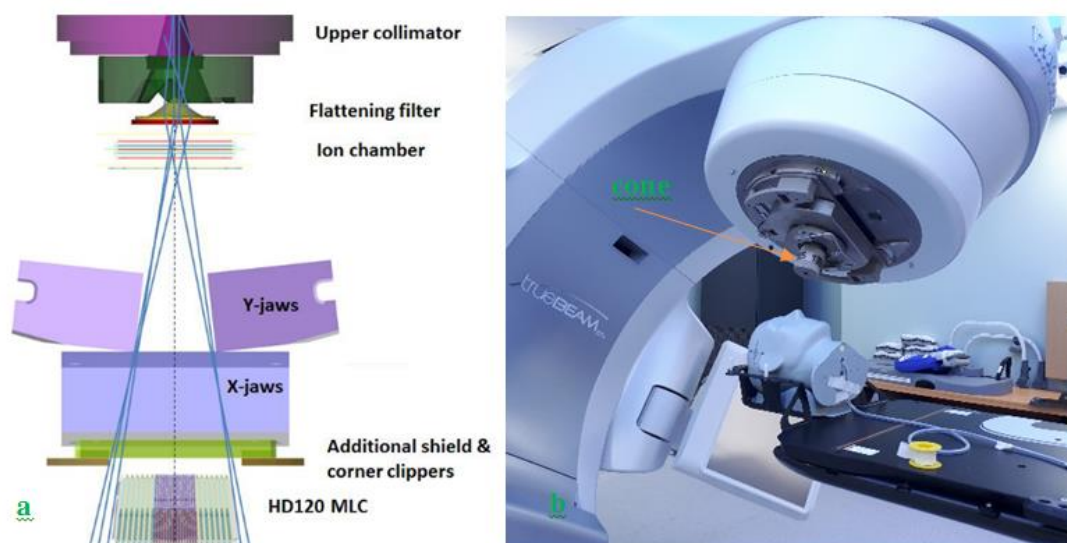


Fig. 2. TrueBeam STx treatment head with collimation systems: a) Jaws (highest), HDMLC (middle) [10] and b) Cone (lowest)

II. MATERIAL AND METHOD

TrueBeamSTx medical linear accelerator with integrated HDMLC with 20 central leaf pairs of 2.5 mm thickness and 40 peripheral leaf pairs of 5.0 mm thickness at isocenter. Beam shaping using HDMLC (and also jaws) were of field sizes 0.5×0.5 , 1×1 , 2×2 , 3×3 , 4×4 , 5×5 , 7×7 , 10×10 cm². MLC-shaped fields were created when the jaws were “optimized” and at “recommended positions” by software. Inversely, jaw-shaped fields were created when MLC are fully retracted. Beam shaping using the cones were with diameter of 4.0, 5.0, 7.5, 10.0, 12.5, 15.0 and 17.5 mm. Photon beam energies of 6X (with Flattening Filter), 6XFFF (Flattening Filter-Free), 10X, 10XFFF were used for measurements. The linac was calibrated for all photon energies at 10×10 cm² jaw-shaped field to be used for all other collimation systems.

The dose measurements were performed in Blue Phantom 2 (IBA) using a Razor chamber (IBA) and Razor diode (IBA) under Source-to-Axis Distance setup (100 cm SAD, 5 cm depth). The TRS398 and TRS483 CoP are both applied to determine relative output factors. Relative output factor curves were compared for 3 different collimation systems and in both CoPs. All data were normalized to 10×10 cm² field size. The equivalent square of the cone defined fields were calculated using formula [2] :

$$S_{clinical} = \sqrt{A \times B} = r\sqrt{\pi} \quad (1)$$

Razor diode (unshielded, p-type silicon diode chip, active detector diameter of 0.6 mm) with high spatial resolution and high sensitivity is superior to Razor chamber (total active length of 3.6 mm) in relative dosimetry of small photon beams. However, Razor diode

has an over-response in large fields because of the significant amount of phantom scatter component of low energy photons. The consequence is an underestimation of field output factors when they are normalized to a large field size (e.g. the conventional $10 \text{ cm} \times 10 \text{ cm}^2$ reference field) [2].

According to TRS398 CoP, the output factor may be determined as the ratio of corrected dosimeter readings measured under a given set of non-reference conditions to that measured under reference conditions. However, in TRS483 CoP, the field output factor, $\Omega_{Q_{clin}, Q_{msr}}^{f_{clin}, f_{msr}}$, relative to f_{msr} is defined by the following equation :

$$\Omega_{Q_{clin}, Q_{msr}}^{f_{clin}, f_{msr}} = \frac{M_{Q_{clin}}^{f_{clin}}}{M_{Q_{msr}}^{f_{msr}}} k_{Q_{clin}, Q_{msr}}^{f_{clin}, f_{msr}} \quad (2)$$

Where $M_{Q_{clin}}^{f_{clin}}$ and $M_{Q_{msr}}^{f_{msr}}$ are the readings of the detector (corrected for influence quantities) in the clinical field (f_{clin}) and the machine specific reference field (f_{msr}), respectively. $k_{Q_{clin}, Q_{msr}}^{f_{clin}, f_{msr}}$ is a beam quality correction factor which changed by field size.

The intermediate field (f_{int}) method was used by applying formula (2) for field sizes bigger than f_{int} measured by Razor ionization chamber, and field sizes smaller than f_{int} measured by Razor unshielded diode for using formula (2):

$$\Omega_{Q_{clin}, Q_{msr}}^{f_{clin}, f_{msr}} = \left[\frac{M_{Q_{clin}}^{f_{clin}}}{M_{Q_{int}}^{f_{int}}} k_{Q_{clin}, Q_{int}}^{f_{clin}, f_{int}} \right]_{det} \left[\frac{M_{Q_{int}}^{f_{int}}}{M_{Q_{msr}}^{f_{msr}}} k_{Q_{int}, Q_{msr}}^{f_{int}, f_{msr}} \right]_{IC} \quad (3)$$

where “det” refers to the small field detector (Razor diode) and “IC” to the ionization chamber (Razor chamber). The output correction factor $\left[k_{Q_{clin}, Q_{int}}^{f_{clin}, f_{int}} \right]_{det}$ is

obtained from the tabulated output correction factors with respect to the machine specific reference field as below:

$$\left[k_{Q_{clin}, Q_{int}}^{f_{clin}, f_{int}} \right]_{det} = \frac{\left[k_{Q_{clin}, Q_{msr}}^{f_{clin}, f_{msr}} \right]_{det}}{\left[k_{Q_{int}, Q_{msr}}^{f_{int}, f_{msr}} \right]_{det}} \quad (4)$$

III. RESULTS and DISCUSSION

A. Output factors of collimation systems using TRS398 CoP

Using the conventional formula from TRS398 CoP, we got the result as Table I.

Table I. Output factors of collimation systems using TRS398 CoP and Razor chamber.

Cone (mm)	4	5	7.5	10	12.5	15	17.5	100 (square)
6X	0.420	0.523	0.662	0.746	0.797	0.834	0.859	1
6XFFF	0.473	0.574	0.702	0.772	0.816	0.846	0.866	1
MLC FS (mm)	0.5	1	2	3	4	5	7	10
6X	0.529	0.754	0.861	0.895	0.921	0.940	0.968	1
6XFFF	0.560	0.782	0.876	0.909	0.932	0.948	0.975	1
Jaw FS (mm)	0.5	1	2	3	4	5	7	10
6X	0.345	0.704	0.850	0.888	0.914	0.936	0.967	1
6XFFF	0.377	0.736	0.867	0.906	0.929	0.947	0.974	1

B. Output factor of collimation systems using TRS483 CoP

Intermediate field (f_{int}) of 4×4 cm² was selected for calculation of jaw-shaped fields and MLC-shaped fields. For

cone, intermediate field was 17.5 mm conical field because we need to normalize these data to that of 10×10 cm² field size. The results were obtained as Table II.

Table II. Output factor of collimation systems using TRS483 CoP (Razor chamber and Razor diode)

Cone (mm)	4	5	7.5	10	12.5	15	17.5	100 (square)
Square Equi. Field size (cm)	0.708	0.885	1.327	1.77	2.212	2.655	3.097	10
6X	0.522	0.599	0.713	0.773	0.814	0.841	0.864	1
6XFFF	0.578	0.648	0.745	0.797	0.830	0.856	0.871	1
MLC Field size(mm)	0.5	1	2	3	4	5	7	10
6X	0.608	0.774	0.871	0.905	0.927	0.945	0.971	1
6XFFF	0.643	0.792	0.881	0.918	0.938	0.954	0.978	1
Jaw Field size(mm)	0.5	1	2	3	4	5	7	10
6X	0.619	0.756	0.84	0.876	0.901	0.924	0.961	1
6XFFF	0.652	0.771	0.846	0.884	0.907	0.928	0.963	1

C. Comparison of results between TRS483 and TRS398 CoP

Based on these results, the difference between ROF curves is significant between the two different methods (CoPs) for MLC-shaped

field size and for jaw-shaped field size less than 3×3 cm for both the 6X and 6XFFF beams.

The smallest difference was observed with MLC-shaped fields while the biggest difference was observed with cone-shaped

fields as seen in Fig.3 and Fig.4. At 0.5×0.5 cm² squared field and 4 mm conical field, the output factor difference of 6X and 6XFFF beams were -44.2%/-42.2%, -13.0%/-13.0%, -19.6%/-18.2% for jaw-shaped, MLC-shaped

and cone-shaped fields, respectively. TRS398 CoP gave underestimation of a relative output factor in comparison with TRS483 CoP. The large difference was always seen at field sizes smaller than 4×4 cm².

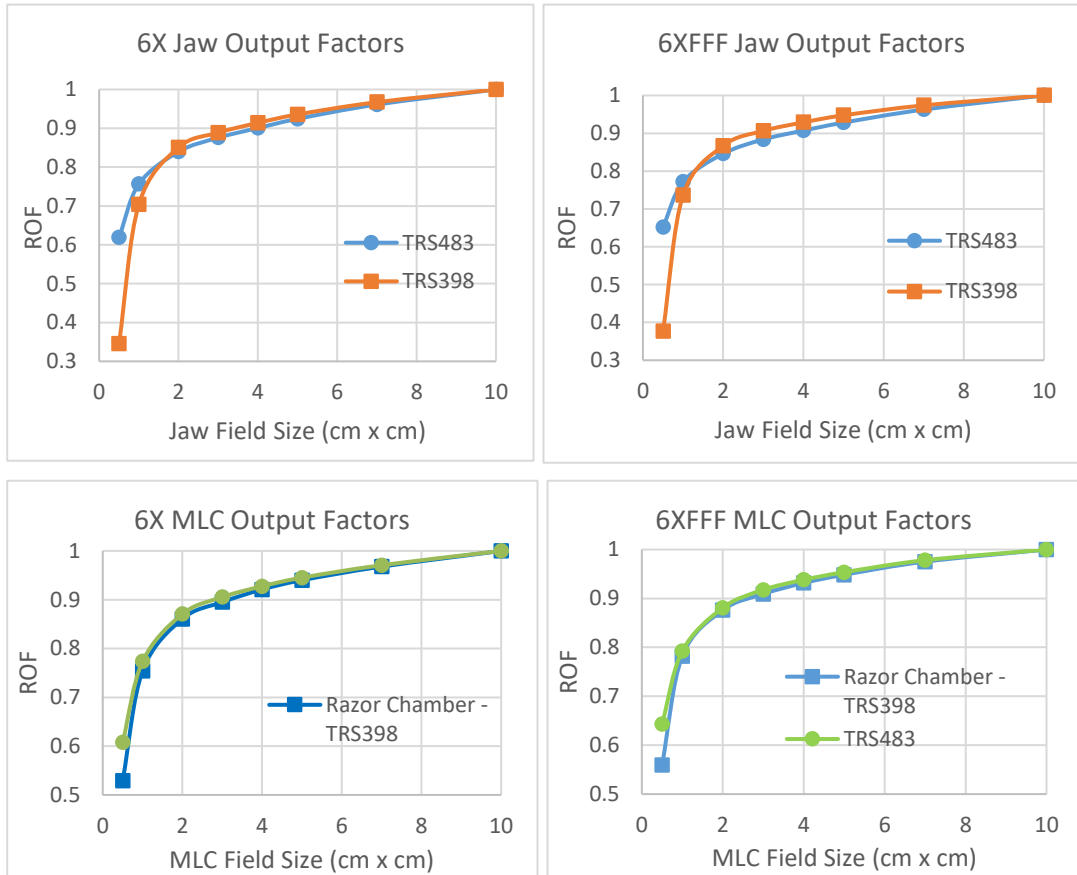


Fig. 3. Difference of TRS398 and TRS483 CoP in relative output factor of MLC and Jaws collimations

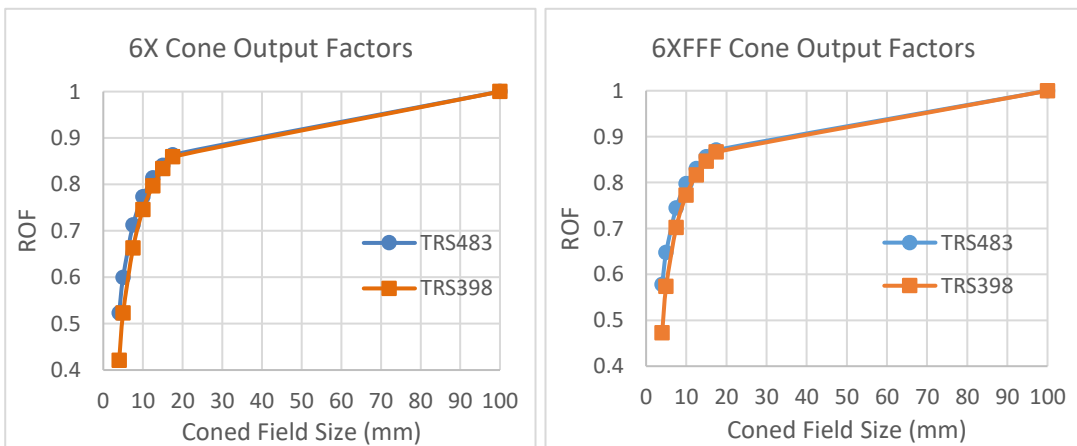


Fig. 4. Difference of TRS398 and TRS483 CoP in relative output factor of cone collimations

Noticingly, the Razor chamber's reading differences between $10 \times 10 \text{ cm}^2$ MLC-shaped field and $10 \times 10 \text{ cm}^2$ jaw-shaped field were just 0.61% and 0.25% for 6X and 6XFFF, respectively. Therefore, these relative output factors could be used for direct comparison between jaw-shaped field and MLC-shaped field of "the same" nominal field size.

D. Comparison of results between 6X, 6XFFF (TRS483 CoP)

For the same collimation system, output factor comparisons were also made for 6X and 6XFFF beams after applying TRS483 CoP (Fig. 5). The biggest differences in output factor were seen at $0.5 \times 0.5 \text{ cm}^2$ jaw-shaped field, $0.5 \times 0.5 \text{ cm}^2$ MLC-shaped field and 4mm cone-shaped field with values of 5.3%, 5.8% and 10.5%, respectively.

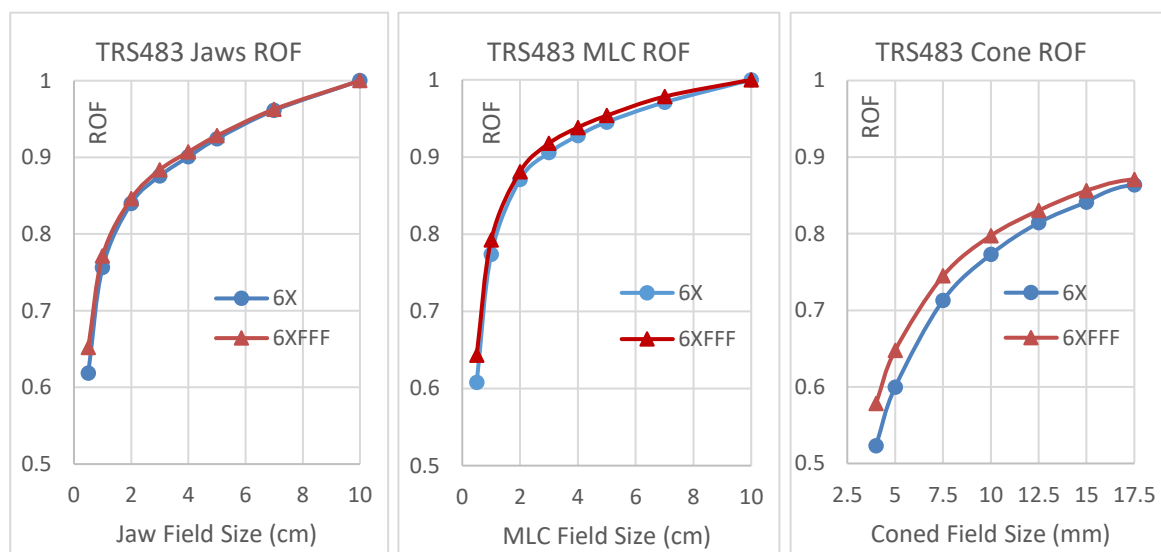


Fig. 5. Difference in output factor of 6X and 6XFFF beams in each collimation system

E. Comparison of Output Factor curves between different collimation systems (TRS483 CoP)

The relative output factor comparisons were made between MLC, jaws and Cone systems for both 6X and 6XFFF beams.

Conical collimators are independent from MLC and Jaws systems. The conical collimation system has smallest relative output factor in comparison with that of MLC and Jaws systems for both 6X and 6XFFF beams as Fig. 6.

For field sizes bigger than $1 \times 1 \text{ cm}^2$, jaw system has lower relative output factor than

MLC's but it is inverse for field size less than $1 \times 1 \text{ cm}^2$.

In a multi-centre analytical study of small field output factor calculations in radiotherapy reported by Krzysztof Chełmiński and Wojciech Bulski, for $2 \times 2 \text{ cm}^2$ MLC-shaped fields of Varian linacs, the differences between the treatment planning system output factors (based on collected beam data) often exceeded 5% and were below 10% [11]. In our study, these differences were -1.1% (6X) and -0.5% (6XFFF) for MLC-shaped fields, 1.3% (6X) and 2.6% (6XFFF) for jaw-shaped fields, -7.0% (6X) and -5.7% (6XFFF) for cone-shaped fields. The smaller differences

observed in our study for MLC-shaped field may come from our small field detector, the Razor chamber.

A multinational audit of small field output factors calculated by treatment planning systems used in radiotherapy, the ROF for small fields calculated by TPSs were generally larger than measured reference data. On a national level, 30% and

31% of the calculated ROF of the $2 \times 2 \text{ cm}^2$ field exceeded the action limit of 3% for nominal beam energies of 6 MV and for nominal beam energies higher than 6 MV, respectively [12].

The discrepancy above may come from accuracy of treatment planning algorithms on measured output factors, especially for small fields.

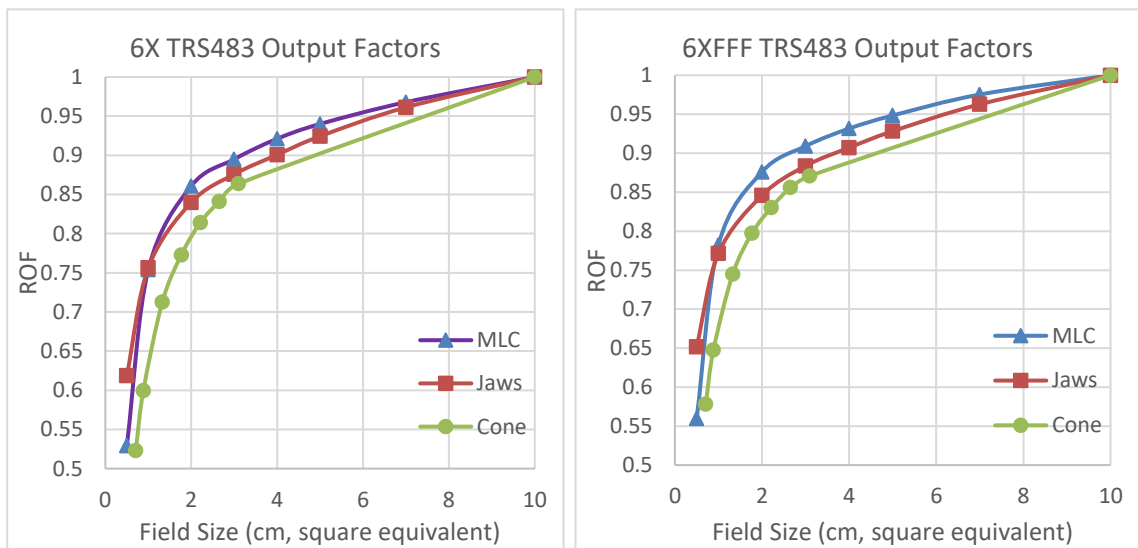


Fig. 6. Difference in output factor of difference collimation system for 6X and 6XFFF beams

CONCLUSIONS

An international code of practice for the dosimetry of small static fields used in external beam radiotherapy (TRS483 CoP) was successfully applied to recalculate relative output factors for cone system with correction. Relative output factors for jaw collimation system were extensively obtained for field size less than $3 \times 3 \text{ cm}^2$ for Eclipse v.13.6 for 6X and 6XFFF beams using TRS483 CoP. Relative output factors were also measured for MLC collimation system to be compared with that of the jaw collimation system. The discrepancy of output factor between jaw-shaped fields and MLC-shaped fields suggests

that jaw-based beam data itself may not be suitable for MLC-based treatment planning. Additional measurement of small beam percentage depth dose and profiles as well as specific modelling of photon beam for MLC system may be required.

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