Journal of
Radiotherapy
in Practice

*Journal of Radiotherapy in Practice* (2018)
**17**, 292–296 © Cambridge University Press 2017
doi:10.1017/S1460396917000681

## Original Article

# Total scatter factor for small fields in radiotherapy: a dosimetric comparison

Qurat-ul-ain Shamsi[1], Saeed Ahmad Buzdar[1], Saima Altaf[1], Atia Atiq[1], Maria Atiq[1], Khalid Iqbal[2]

[1]*Physics Department, The Islamia University of Bahawalpur, Bahawalpur,* [2]*Clinical & Radiation Oncology Department, Shaukat Khanum Memorial Cancer Hospital and Research Center, Lahore, Punjab, Pakistan*

(Received 3 October 2017; Received 19 October 2017; accepted 22 October 2017; first published online 27 November 2017)

## Abstract

*Purpose:* Small field dosimetry is complicated and accuracy in the measurement of total scatter factor (TSF) is crucial for dosimetric calculations, in making optimum intensity-modulated radiotherapy plans for treating small target volumes. In this study, we intended to determine the TSF measuring properties of CC01 and CC04 detectors for field sizes ranging from sub-centimetre to the centimetre fields.

*Material and methods:* CC01 and CC04 chamber detectors were used to measure TSF for 6 and 18 MV photon beam delivered from the linear accelerator, through small fields in a water phantom. Small fields were created by collimator jaws and multi-leaf collimators separately, with field sizes ranging from 0·6 to 10 cm$^2$ and 0·5 to 20 cm$^2$, respectively.

*Results:* CC01 measured TSF at all the given field sizes created by jaws and multi-leaf collimators for both 6 and 18 MV beams whereas CC04 could not measure TSF for field sizes <1 cm$^2$ due to volume averaging and perturbation effects.

*Conclusion:* CC01 was shown to be effective for measurement of TSF in sub-centimetre field sizes. CC01 can be employed to measure other dosimetric quantities in small fields using different energy beams.

*Keywords*: chamber detectors CC01 and CC04; collimator jaws; linear accelerator; multi-leaf collimators; small field dosimetry

## INTRODUCTION

Advanced radiotherapy techniques like intensity-modulated radiation therapy (IMRT), volumetric modulated arc therapy and stereotactic radiosurgery deliver highly localised beam doses to the target volumes with enhanced accuracy by applying very small beam orifices to achieve the clinical targets of radiotherapy.[1] But, such small fields possess high dose gradients and disequilibrium of the charged particles, thus, making small field dosimetry complicated.

As defined by Sharma, the small fields are the one having dimensions less than the lateral range of the charged particles which contributes in dose

---

Correspondence to: Qurat-ul-ain Shamsi, Physics Department, The Islamia University of Bahawalpur, Bahawalpur, Punjab 63100, Pakistan. E-mail: annieshamsi@hotmail.com. Tel: +92622875063.

deposition at a point that lies along the beam central axis.[2] Other authors have also described the small fields on the basis of charge disequilibrium, size of the source and the choice of a detector, in the literature.[3–5] According to Institute of Physics and Engineering in Medicine report, radiation fields with dimensions <40 mm$^2$ fall under small photon field category.[4]

There are a number of detectors like compact chambers, plastic scintillator detectors and the EBT films that are employed in the measurement of dosimetric quantities in small fields. Several authors have written on the properties of a good detector and the multiple limitations associated with various types of detectors in the literature.[6–9]

As stated by Azimi et al., an accuracy in the measurement of total scatter factor (TSF) in small fields is important for dose calculations in treatment planning systems especially when small targets are treated with IMRT.[10]

The measurement of TSF is important for the calculation of monitor units (MUs) in order to ensure the precise delivery of radiation dose to the target volume. But there presented a little published data on the measurement of TSF through chamber detectors like CC01 and CC04 in small fields. This study is based on the measurement of TSF of 6 and 18 MV photon beams delivered from a Varian linear accelerator, at various field sizes by using CC01 and CC04 detectors in a water phantom.

## MATERIALS AND METHODS

In this study, two compact chamber detectors CC01 and CC04 from IBA Dosimetry America (Bartlett, TN, USA) were used for the measurements of TSF for 6 and 18 MV photon beam delivered from a Varian linear accelerator (Palo Alto, CA) Clinac 21EX, at a dose rate of 300 MU/minute and it was equipped with Millennium 120 multi-leaf collimator (MLC). CC01 consisted of sensitive diameter of 2 mm and sensitive length of 3 mm. CC04 detector had sensitive diameter of 4 mm and sensitive length of 3·6 mm. Field sizes for both the photon beams, were defined by using two arrangements. In first arrangement, X-Y collimator jaws were used to define the field sizes ranging from 0·6, 0·8, 1·0, 1·2, 1·5, 2·0, 2·5, 3·0, 4·0, 5·0, 6·0, 8·0 and 10·0 cm$^2$. In second arrangement, MLCs formed the squared fields with the sizes ranging from 0·5, 1·0, 1·5, 2·0, 2·5, 3·0, 4·0, 5·0, 6·0, 8·0 and 20·0 cm$^2$. Both energy beams were made to fall into a $40 \times 40 \times 40$ cm$^3$ water phantom (CNMC Company Inc., Nashville, TN, USA) which had a vertical translation stage attached on one of the walls. CC01 and CC04 detectors were attached to the stage and positioned such that the measurement point of the detectors remained at beam isocenter at the depth of 10 cm in a water phantom. An SSD (source-to-surface distance) was kept at 90 cm.

## RESULTS

In advanced radiotherapy techniques, the measurement of the dosimetric parameters is important in making optimum treatment plans for small-sized targets. TSF is among the dosimetric parameters which are essential in the calculation of the MUs needed to deliver prescribed radiation doses to the target volumes.[11]

The results for the measurements of TSF of 6 and 18 MV photons are divided into two sections on the basis of two different types of collimator fields (collimator jaws and MLCs).

(1) Measurement of TSF of 6 and 18 MV beam through jaw fieldsIn first section, TSF was measured by the detectors CC01 and CC04 for 6 and 18 MV photon beams from a Varian linear accelerator through the jaw fields with dimensions varying from 0·6 to 1 cm$^2$.Table 1 shows the measurement of TSF for 6 and 18 MV energy beam by employing jaw fields ranging from 0·6 to 10 cm$^2$. CC01 and CC04 were used for the measurement of TSF. CC01 detector measured TSF for all the given field sizes. CC04 did not measure scattering for the field sizes <1·0 cm$^2$ due to perturbation and volume averaging effects.[12] TSF increased with the increasing field sizes as measured by both detectors.[13]For 18 MV beam, both detectors measured TSF for the same set of field sizes as for 6 MV beam. CC01

***Table 1.*** *Measurement of total scatter factor (TSF) of 6 and 18 MV beam through jaw fields*

| 6 MV beam through jaw field | | | 18 MV beam through jaw field | | |
|---|---|---|---|---|---|
| Field size (cm$^2$) | TSF by CC01 | TSF by CC04 | Field size (cm$^2$) | TSF by CC01 | TSF by CC04 |
| 0·6 | 0·540 | 0 | 0·6 | 0·420 | 0 |
| 0·8 | 0·630 | 0 | 0·8 | 0·505 | 0 |
| 1 | 0·670 | 0·660 | 1 | 0·560 | 0 |
| 1·5 | 0·750 | 0·740 | 1·5 | 0·680 | 0·675 |
| 2 | 0·780 | 0·780 | 2 | 0·752 | 0·752 |
| 3 | 0·821 | 0·830 | 3 | 0·840 | 0·840 |
| 4 | 0·860 | 0·865 | 4 | 0·890 | 0·890 |
| 5 | 0·890 | 0·892 | 5 | 0·920 | 0·920 |
| 6 | 0·920 | 0·920 | 6 | 0·942 | 0·942 |
| 8 | 0·965 | 0·965 | 8 | 0·978 | 0·978 |
| 10 | 1 | 1 | 10 | 1 | 1 |

***Table 2.*** *Measurement of total scatter factor (TSF) of 6 and 18 MV through multi-leaf collimator (MLC) fields*

| 6 MV beam through MLC field | | | 18 MV beam through MLC field | | |
|---|---|---|---|---|---|
| Field size (cm$^2$) | TSF by CC01 | TSF by CC04 | Field size (cm$^2$) | TSF by CC01 | TSF by CC04 |
| 0·5 | 0·540 | 0 | 0·5 | 0·410 | 0 |
| 1 | 0·710 | 0·700 | 1 | 0·610 | 0·600 |
| 1·5 | 0·780 | 0·780 | 1·5 | 0·720 | 0·720 |
| 2 | 0·820 | 0·820 | 2 | 0·800 | 0·80 |
| 3 | 0·870 | 0·870 | 3 | 0·890 | 0·890 |
| 4 | 0·900 | 0·900 | 4 | 0·940 | 0·940 |
| 5 | 0·930 | 0·930 | 5 | 0·970 | 0·970 |
| 10 | 1·029 | 1·029 | 10 | 1·025 | 1·025 |
| 15 | 1·080 | 1·080 | 15 | 1·055 | 1·055 |
| 20 | 1·110 | 1·110 | 20 | 1·060 | 1·060 |

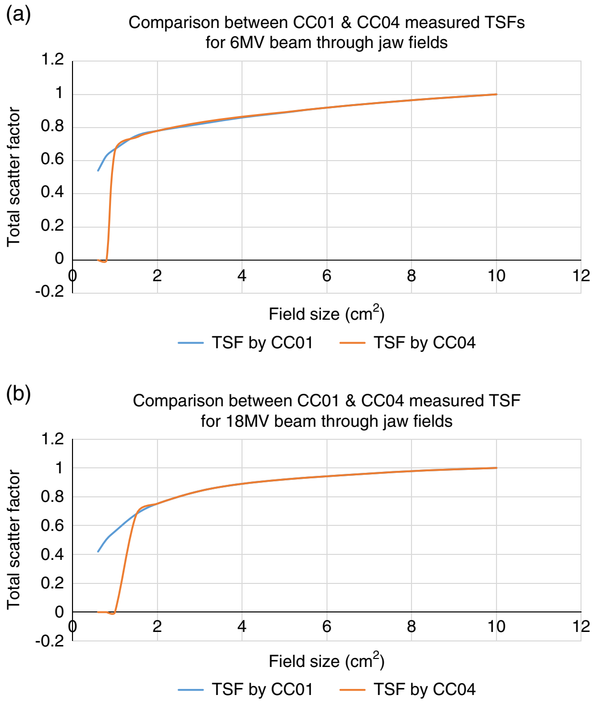

*Figure 1. (a) Comparison between CC01 and CC04 measured total scatter factor (TSF) for 6 MV beam through jaw field. (b) Comparison between CC01 and CC04 measured TSF for 18 MV beam through jaw field.*

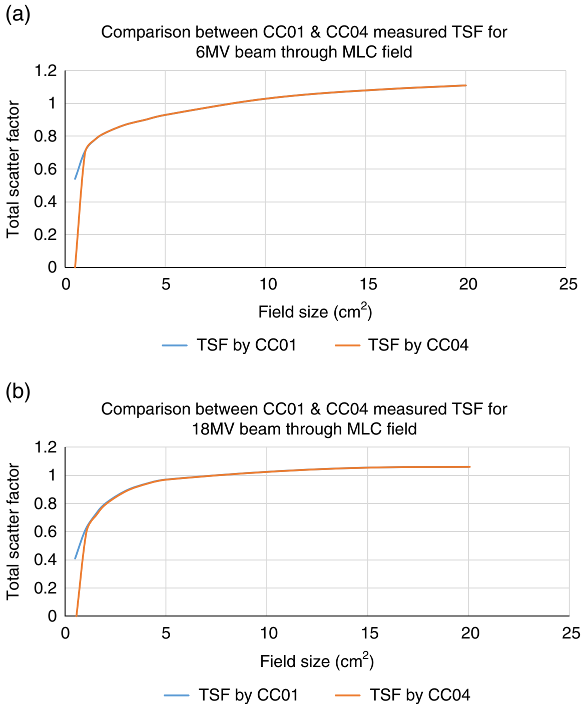

*Figure 2. (a) Comparison between CC01 and CC04 measured total scatter factor (TSF) for 6 MV beam through multi-leaf collimator (MLC) field. (b) Comparison between CC01 and CC04 measured TSF for 18 MV beam through MLC field.*

measured scattering for all the given field sizes. TSF for 18 MV beam is slightly less than that for 6 MV for the field sizes ranging from 0·6 to 2 cm$^2$ because of the decrease in the probability of scattering of higher energy beam as compared with lower energy beam but the scattering of higher energy beam also increases with the increasing field sizes.[14] CC04 did not measure scattering for the field sizes smaller than 1·5 cm$^2$ due to reason given above (Figure 1a and 1b).

(2) Measurement of TSF of 6 and 18 MV beam through MLC fields

In second section, TSF measurements were carried out using CC01 and CC04 for 6 and 18 MV photon beams through the MLCs with field sizes ranging from 0·5 to 20 cm$^2$.

In Table 2, CC01 measured scattering for all the given field sizes for both 6 and 18 MV beam but CC04 did not show any TSF value for field size <1 cm$^2$ again due to volume averaging and perturbation effects. TSF measured through MLCs was higher as compared with that measured through jaw fields due to the increased scattering in the collimator leaves and leakage between the closed leaves.[15] TSF is higher for 6 MV beam because leakage through MLC leaves is higher for lower energy beam as studied by Jabbari et al.[16] The above given results are presented graphically in Figure 2a and 2b.

## DISCUSSION

Several challenges in small field dosimetry exist, including lack of charged particle equilibrium, overestimation of field size, perturbation of the particle fluency in the chamber and volume averaging effect of the detector. The radiation detectors are capable of averaging the dose over their volume. When the radiation beam dose changes over the detector volume, then the averaging may cause a different signal in comparison with the signal that any small detector would measure in the central area of a large detector and it gives rise to volume averaging effect as defined by Weurfel.[17]

The volume averaging effects and perturbation appeared because of the finite size of the sensitive volume of the detector, lateral charge disequilibrium and also due to non-water equivalency of the detectors, as documented by various authors in the literature.[18,19] In comparison with CC01 detector, CC04 detector is not capable of measuring dosimetric quantities and scatter factors like TSF, for field sizes <1 cm$^2$ using 6 and 18 MV beams in this study, because of the larger perturbation and volume averaging effects.[20,21]

There occurred differences in the TSFs, measured by CC01 and CC04 due to differences in the active volumes of the two types of the detector. This type of discrepancy was also observed by Muhammad Kamran et al. They analysed the TSFs for 6 and 15 MV photon beams by using CC01 and CC13 detectors. They found underestimation in the measurement of TSF by CC13 due to larger volume averaging and disequilibrium of the charged particles, as compared with CC01.[12]

Reduan et al., discussed about the minimum scattering of photons through small field sizes due to reduced lateral scattering of the photons from the primary beam and it becomes greater for the larger field sizes.[22] This study also revealed that TSF went on increasing with the field sizes whether they are formed by the collimator jaws or by the MLCs because the increased collimator openings cause more scattering of the photon beam.[23] Arnfield et al., in their findings showed that the scattering by the leaves of MLCs increased with the increasing field sizes because the greater MLC surface area got exposure to the photon beam.[24]

## CONCLUSION

In this exploration, CC01 detector measured TSF at all the given field sizes for both the energy beams whereas CC04 could not measure TSF for the field sizes <1 cm$^2$ due to volume averaging and perturbation effects. CC01 was shown to be effective for measurement of TSF in subcentimetre field sizes. CC01 can be employed to measure other dosimetric quantities in small fields using different energy beams.

### Acknowledgement

The authors would like to acknowledge the Department of Radiation Physics M D Anderson Cancer Centre, University of Texas, Houston USA and the Department of Clinical of Clinical and Radiation Oncology, Shaukat Khanum Memorial Cancer Hospital and Research Centre, Lahore, Punjab, Pakistan.

### Conflicts of Interest

None.

## References

1. Chaudhari S H, Dobhal R, Kinhikar R A, Kadam S S, Deshpande D D. Measurement of total scatter factor for stereotactic cones with plastic scintillation detector. J Med Phys 2017; 42 (1): 9–13.
2. Sharma S D. Challenges of small photon field dosimetry are still challenging. J Med Phys 2014; 39 (3): 131.
3. Das I J, Ding G X, Ahnesjö A. Small fields: nonequilibrium radiation dosimetry. Med Phys 2008; 35: 206–215.
4. Aspradakis M, Byrne J, Palmans H et al Small field MV photon dosimetry. IPEM Report No. 103. York, UK: Institute of Physics and Engineering in Medicine, 2010.
5. Das IJ, Morales J, Francescon P. Small field dosimetry: What have we learnt? In Massillon-JL G, Fossion R, Mendez IM, Avila-Rodriguez MA, López-Pérez DO (eds). AIP Conference Proceedings, Volume 1747, No. 1. Indianapolis, IN, USA: AIP Publishing, 2016: 060001.
6. Francescon P, Cora S, Cavedon C, Scalchi P, Stancanello J. CyberKnife dosimetric beam characteristics: comparison between experimental results and Monte Carlo simulation Robot. Radiosurgery 2005; 1 (1): 71–80.
7. Francescon P, Kilby W, Satariano N. Monte Carlo simulated correction factors for output factor measurement with the CyberKnife system? Results for new detectors and correction factor dependence on measurement distance and detector orientation. Phys Med Biol 2014; 59: N11–N17.
8. Alfonso R, Andreo P, Capote R et al. A new formalism for reference dosimetry of small and nonstandard fields. Med Phys 2008; 35 (11): 5179–5186.
9. Cranmer-Sargison G, Weston S, Evans J A, Sidhu N P, Thwaites D I. Implementing a newly proposed Monte Carlo based small field dosimetry formalism for a comprehensive set of diode detectors. Med Phys 2011; 38: 6592–6602.
10. Azimi R, Alaei P, Higgins P. The effect of small field output factor measurements on IMRT dosimetry. Med Phys 2012; 39 (8): 4691–4694.
11. Birgani M J, Chegeni H, Behrooz M A, Bagheri M, Danyaei A, Shamsi A. An analytical method to calculate phantom scatter factor for photon beam accelerators. Electron Physician 9 (1): 3523–3528.
12. Nasir M K, Amjad N, Razzaq A, Siddique T. Measurement and analysis of PDDs profile and output factors for small field sizes by CC13 and micro-chamber CC01. Int J Med Phys Clin Eng Radiat Oncol 2017; 6 (01): 36.
13. Podgorsak E B. Radiation Oncology Physics: A Handbook for Teachers and Students. Vienna: International Atomic Energy Agency, 2005.
14. Khan F M, John P G. Khan's the Physics of Radiation Therapy. Philadelphia, PA: Lippincott Williams & Wilkins, 2014.
15. Arnfield M R, Siebers J V, Kim J O, Wu Q, Keall P J, Mohan R. A method for determining multileaf collimator transmission and scatter for dynamic intensity modulated radiotherapy. Med Phys 2000; 27 (10): 2231–2241.
16. Jabbari K, Akbari M, Tavakoli M B, Amouheidari A. Dosimetry and evaluating the effect of treatment parameters on the leakage of multi leaf collimators in ONCOR linear accelerators. Adv Biomed Res 2016; 5 (1): 193–200.
17. Würfel J U. Dose measurements in small fields. Med Phys 2013; 1 (1): 81–90.
18. Godson H F, Ravikumar M, Sathiyan S, Ganesh K M, Ponmalar Y R, Varatharaj C. Analysis of small field percent depth dose and profiles: comparison of measurements with various detectors and effects of detector orientation with different jaw settings. J Med Phys 2016; 41 (1): 12.
19. Apipunyasopon L, Srisatit S, Phaisangittisakul N. An investigation of the depth dose in the build-up region, and surface dose for a 6-MV therapeutic photon beam: Monte Carlo simulation and measurements. J Radiat Res 2013; 54: 374–382.
20. Tyler M K, Liu P Z, Lee C, McKenzie D R, Suchowerska N. Small field detector correction factors: effects of the flattening filter for Elekta and Varian linear accelerators. J Appl Clin Med Phys 2016; 17 (3): 223–235.
21. Azangwe G, Grochowska P, Georg D et al. Detector to detector corrections: a comprehensive experimental study of detector specific correction factors for beam output measurements for small radiotherapy beams. Med Phys 2014; 41 (7): 072103.
22. Reduan Aa, Mazurawati Mb, Nur Iziana Ma, Nik Ruzman NIb, Ahmad Za, Ahmad Lutfi Yb. Verification of relative output factor (ROF) measurement for radiosurgery small photon beams. Health Environ J 2016; 7 (2): 20–31.
23. Washington C M, Dennis T. Leaver. Principles and Practice of Radiation Therapy. Amsterdam: Elsevier Health Sciences, 2015: 483–484.
24. Arnfield M R, Siebers J V, Kim J O, Wu Q, Keall P J, Mohan R. A method for determining multileaf collimator transmission and scatter for dynamic intensity modulated radiotherapy. Med Phys 2000; 27 (10): 2231–2241.