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Comparison of the scatter factor with various configurations and its impact on the precision of dose calculation

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ABSTRACT

Background: The purpose of this study is to contrast the output factors using non-identical detectors with different setups and their effect on the plan of therapy. ***Materials and Methods***: The measurements were obtained for 6MV beams with various volume chambers using Varian True beam™ STx linear accelerator (LINAC). With chambers set up at source to axis distance (SAD) and source to surface distance (SSD) at two different depths, the output factors were measured (both 5 and 10 cm). The smallest output factors were assessed with the SAD technique at 5 cm of depth and the largest output factor was observed with the SSD approach at 10 cm depth and had been moved to the system for treatment planning and variation in calculated and measured dose was noted. ***Results***: A variation in measured dose from Treatment Planning System (TPS) calculated ranges from 0 to -2.7 % for small field plans calculated with SAD technique and -0.22 to -2.31 % for plans calculated with SSD technique. For large fields, it ranges from -0.89 to 0.8 % for SAD and -0.6 to 0.64 % for the SSD technique. The Statistical significance was checked and was found to be greater than 0.05. ***Conclusion***: The percentage difference in output factors at two depths was more prominent for low energy beams (6 MV) than for beams of greater energy. This might be a result of the loss of lateral equilibrium as the depth is changed. The output factor measurement at 10 cm of depth and 100 cm SSD is suitable for small fields (3 x 3 cm^2) as it increases the lateral equilibrium and hence reduces the error.

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INTRODUCTION

One of the essential factors determining Monitor Units (MU) in radiotherapy treatment planning is the scatter factor. There are two scatter factors: the Scatter factor (Sc) and the Phantom Scatter factor for the Collimator (Sp). The Sc,p, the total scatter factor includes the scattering of both collimator and phantom. It is defined as the product of collimator and phantom scatter. Earlier, most treatment planning systems (TPS) require separate Sc, Sp, and Sc,p. However now a day TPS requires only a total scatter factor, which can be measured easily with a water phantom with a chamber at 5 cm/10 cm depth, and meter readings were taken for different field sizes, and the ratio of each field to that of standard field (10 × 10 cm^2) is entered into the TPS. Numerous research [1–9] have evaluated small field output factors with various detectors, and numerous [10–11] have examined the effects of small field output factor correction in dosage calculation and delivery. Iftikhar 2012 [15] measured the output variables using various ionization chambers with different build-up caps for two energies using Varian Clinac 2100 LINAC.

Similarly, Sendani *et al.* [10] 2019 measured output factors for the field sizes determined by the MLC alone, the MLC + jaws, and the jaws alone. They measured the output factors at 5 cm depth and generated three sets of output factors, one with the corrected output factor as per TRS 483, the second without any correction for small fields, and the third one with the smallest field size 3×3 cm^2. Moreover, these data were modeled separately in different treatment planning algorithms. The study's findings showed that corrected output factors for fields less than 2×2 cm^2 increase the accuracy of dose calculation. The accuracy for less than 1×1 cm^2 is impacted by the resilience of the dose calculation algorithm. Hence the corrected output factors are used for lower field sizes (less than 2×2 cm^2).

Similar research was conducted by Azimi *et al.* (2012) [11], who investigated the effects of changes in confined field output variables on the doses utilized in intensity-modulated treatment planning (IMRT). They changed the output factors of 2×2 cm^2 and 3×3 cm^2 by ±5 %, ±10 %, and ±20 % from their baseline value. They discovered that by reducing the output factors in the Elekta LINAC, the measured doses were greater than computed doses for steps of 5.0%, 10.0%, and 20.0% by 0.8%, 3.6%, and 8.7%, respectively. Lower doses of 2.9%, 5.4%, and 8.3% for +5.0%, +10.0%, and +20.0% steps were obtained by increasing the output factors. No differences were seen for either increased or decreased output factors for the Varian LINAC.

Samuel *et al.* (14) 2020 investigated the effect of field small output factors in TPS commissioning. The PDD profiles were assessed using different chambers, and output factors were collected according to the American Association of Physicists in Medicine (AAPM) code modeled for Acuros XB algorithms and computed the dose in 5 symmetric field sizes, 10 SRS cases planned with 2 fields VMAT and nine fields IMRT where MLC was used to segment tiny fields. The study results revealed that the evaluation of both symmetric fields and clinical cases compared to the calculation depends on the types of detector commissioning and the treatment planning algorithms for a small field.

Fan *et al.* (16) 2009 investigated output factors in such a method compared to chambers, film measurements, and Monte Carlo (MC) simulation. They found that MC and film results agree with measurements applying the scan beam technique in which many narrow beams are employed for measurements. These scan beams form a uniform field that can provide lateral equilibrium. In addition, there is a deconvolution of nearby beams, and output is obtained. The study's findings indicated that a novel approach might be able to accommodate positional uncertainties and detector volume averaging effects. Different authors perform the output factor measurement in different ways. Some authors keep the chamber at 5 cm depth, some at 10 cm depth, and few keep the SSD 100 cm, 90 cm, or 95 cm. It was observed from different journals that there is a variation of output factor by more than 3 % with the setup.

There were few studies on the impact of measurement setup on output factors. Hence this study aims to compare how the setup variation will affect the output factor for different energies and the effect on the treatment planning accuracy of dose calculation, including dynamic and static fields for 6 MV photon beams. The effect of the chamber on the output factor is another scope of this study. The output factors of the six MV beams with different setups were assessed, and the same is loaded into TPS while PDD and profiles remain the same. The dose calculation accuracy is evaluated for small fields and larger fields. For evaluation purposes, ten small fields (3.31 cc - 199.3 cc volume) IMRT plans and ten large field IMRT plans (79.5 cc - 1656.7 cc) were taken. After loading the different output factor tables, these plans were calculated using the same objectives.

MATERIALS AND METHODS

Linear accelerator

The measurements were carried out utilizing the photon and electron beam-delivering Varian Truebeam STx Linear Accelerator. This unit can deliver flattened photon beams (6, 10, and 15 MV) and flattening photon beams without filters (6 FFF and 10FFF). Electron energies of 6Mev, 9Mev, 12 MeV, and 15 MeV can be generated. The collimator of Varian Truebeam STx can generate field sizes from 0.5×0.5 cm^2 till 40×40 cm^2. A high-definition multi-leaf collimator (HDMLC) with 60 pairs of 2.5mm leaf width in the center for 8 cm and the remaining 5mm leaf width in the periphery is a feature of this unit. The largest field that HDMLC can produce is 40 cm by 22 cm.

Dosimeters

PTW's MP3 radiation field analyzer (RFA) and different volume ionization chambers are used for dosimetry. The chamber used for output measurements are PTW's Farmer chamber of 0.6cc volume, semi-flex chamber of 0.125cc volume, and pinpoint chamber of 0.01cc volume. PTW's UNIDOSE E electrometer is used along with these ionization chambers.

Measurement set up

Output factors were measured for both flattening filter (FF) and flattening filter-free (FFF) beams of photon energies such as 6 10 & 15 MV (FF), and 6 & 10 MV (FFF) using PTWs slab phantom with farmer chamber with UNIDOS-E electrometer. The square field output factors (3×3 cm^2, 5×5 cm^2, 7×7 cm^2, 10×10 cm^2, 15×15 cm^2, 20×20 cm^2, 30×30 cm^2 & 40×40 cm^2) defined by Jaws were measured with different chambers at different distance from the target. Taking the measurements was done by keeping the chamber at (i) 5 cm depth with SSD 100 cm, (ii) 5 cm depth with SSD 95 cm, (iii) 10 cm depth with 100 cm of SSD, and (iv) 10 cm depth with 90 cm SSD. The meter readings were noted for different field sizes in the above setups. Moreover, it is scaled down to fit into the relevant 10×10 cm^2 field size meter reading. The same measurements were performed with pinpoint and Semiflex chambers for 6 MV beams to know the variation of output factors with chambers.

With PTW's MP3 RFA, the output factors for 6 MV beams for all field sizes were measured at 5 cm depth for the SAD technique and 10 cm depth for the SSD technique and then modeled for the Anisotropic Analytical Algorithm (AAA) of the Eclipse treatment planning system version 15.6. The same validation is performed on scanned images of slab phantom with fields placed in different setups other than measurement setup and calculated dose using two modeled AAA algorithms. Ten small-field stereotactic and 10 large-field volumetric modulated arc therapy (VMAT) plans were re-planned using two modeled algorithms. Apart from that, 10 three-dimensional radiotherapies (3DCRT) plans and ten intensity modulated Radiation therapy (IMRT) plans were

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recalculated employing the algorithms mentioned above. The monitor units (MU) were noted down for all. Using *t-test*, the statistical analysis was performed for small and large field VMAT cases, 3DCRT, and IMRT cases.

Statistical analysis

The data was analyzed using Microsoft Excel. The paired sample *t-test* which is used to calculate the probability of significant difference between two data sets was performed on the monitor units, which were the data analyzed in the study. If the calculated value is less than 0.05, we can conclude that there is a statistically significant difference between two data sets. However we received the result of 0.40, which indicates that the hypothesis is not that significant and we reject the hypothesis.

RESULTS

Output factors at 5 and 10 cm depth with SAD and SSD method were carried out with Farmer chamber for 6, 10 and 15 MV (FF), and 6 & 10 MV (FFF) beams were tabulated in table 1-5.

Table 1. Output factors measured for 6 MV beams using the SAD and SSD techniques at 5 and 10 cm depth with Farmer chamber.

Field size (cm^2)	5 cm SAD	5 cm SSD	10 cm SAD	10 cm SSD
3 X 3	0.851	0.859	0.805	0.815
5 X 5	0.926	0.926	0.892	0.893
7 X 7	0.963	0.963	0.944	0.944
10 X 10	1.000	1.000	1.000	1.000
15 X 15	1.039	1.039	1.062	1.060
20 X 20	1.065	1.065	1.103	1.100
30 X 30	1.096	1.094	1.152	1.142
40 X 40	1.099	1.096	1.158	1.145

Abbreviations: MV: Megavoltage, SAD: Source to axis distance, SSD: Source to surface distance.

The output factors for low energy X rays (6MV) are measured in table 1 above. This table makes it evident that as field size grows, so does the output factor. When compared to bigger field sizes, the rate of increase was higher for smaller field sizes. The difference between output factor measured at different depth of measurement (5 and 10 cm) was determined to be 0.046 for the SAD approach and 0.044 for the SSD technique. In contrast, for larger field sizes, we discovered a difference of 0.059 for SAD and 0.049 for SSD, demonstrating a bigger difference for SAD when compared to SSD.

The output parameters for medium energy X rays (10MV) are shown in table 2. The difference between the output factor measured at different depth of measurements (5 and 10 cm) was determined to be 0.034 for the SAD approach and 0.026 for the SSD technique. In contrast, we discovered a difference of 0.038 for SAD and 0.03 for SSD method for higher field sizes.

Table 2. Output factors measured using the Farmer chamber with SAD and SSD techniques at 5 and 10 cm depth for 10 MV beams.

Field size(cm^2)	5 cm SAD	5 cm SSD	10 cm SAD	10 cm SSD
3 × 3	0.841	0.852	0.807	0.826
5 × 5	0.933	0.933	0.909	0.910
7 × 7	0.967	0.967	0.954	0.954
10 × 10	1.000	1.000	1.000	1.000
15 × 15	1.033	1.033	1.048	1.046
20 × 20	1.055	1.055	1.079	1.076
30 × 30	1.081	1.079	1.115	1.109
40 × 40	1.083	1.082	1.121	1.112

Abbreviations: MV: Megavoltage, SAD: Source to axis distance, SSD: Source to surface distance.

Table 3. Output factors measured for 15 MV beams using the SAD and SSD techniques at 5 cm and 10 cm depth with Farmer chamber.

Field size(cm^2)	5 cm SAD	5 cm SSD	10 cm SAD	10 cm SSD
3 × 3	0.833	0.846	0.804	0.825
5 × 5	0.933	0.936	0.914	0.917
7 × 7	0.968	0.969	0.959	0.958
10 × 10	1.000	1.000	1.000	1.000
15 × 15	1.029	1.030	1.042	1.040
20 × 20	1.049	1.049	1.069	1.065
30 ×30	1.072	1.072	1.100	1.094
40 × 40	1.075	1.075	1.104	1.096

Abbreviations: MV: Megavoltage, SAD: Source to axis distance, SSD: Source to surface distance.

The output variables for high energy X-rays are measured in table 3 (15 MV). For small field size, a difference of 0.029 was discovered for the SAD approach and 0.021 for the SSD technique when measured against the depth of measurement (5 and 10 cm). In contrast, we discovered a difference of 0.029 for SAD and 0.021 for SSD method for higher field sizes.

According to the aforementioned three tables, the difference between the output factors measured at a depth of 5 and 10 cm was a little high for low energy and decreased as energy increased. For greater energy, the difference was similar for small and large field sizes. Smaller and larger field sizes were observed to differ for higher energy levels.

Table 4. Output factors measured for 6FFF beams using the SAD and SSD techniques at a 5 and 10 cm depth.

Field size (cm^2)	5 cm SAD	5 cm SSD	10 cm SAD	10 cm SSD
3 X 3	0.868	0.875	0.819	0.827
5 X 5	0.938	0.939	0.903	0.902
7 X 7	0.970	0.970	0.950	0.950
10 X 10	1.000	1.000	1.000	1.000
15 X 15	1.029	1.030	1.052	1.051
20 X 20	1.049	1.048	1.084	1.082
30 X 30	1.069	1.067	1.119	1.111
40 X 40	1.071	1.069	1.123	1.113

FFF: Flattening Filter free, SAD: Source to axis distance, SSD: Source to surface distance.

Larger field sizes showed a significant difference when compared to small field sizes for low energy FFF beams, whereas for medium energy FFF beams, larger field sizes showed a lesser difference when compared to small field size for both SSD and SAD

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technique. This was true when the difference between 5 and 10cm depth measured output factors for 6 and 10 FFF beams was compared (table 4 and 5).

The output factors were measured with pinpoint chamber and Semiflex for 6 MV beams and were tabulated in tables 6 and 7.

Table 5. Output factors measured using the Farmer chamber with SAD and SSD techniques at 5 and 10 cm depth for 10 FFF beams.

Field size(cm^2)	5 cm SAD	5 cm SSD	10 cm SAD	10 cm SSD
3 X 3	0.883	0.891	0.845	0.861
5 X 5	0.959	0.960	0.934	0.936
7 X 7	0.981	0.981	0.968	0.969
10 X 10	1.000	1.000	1.000	1.000
15 X 15	1.018	1.017	1.030	1.030
20 X 20	1.029	1.029	1.049	1.048
30 X 30	1.043	1.041	1.068	1.064
40 X 40	1.045	1.044	1.071	1.066

FFF: Flattening Filter free, SAD: Source to axis distance, SSD: Source to surface distance.

Table 6. Output factors determined using the SAD and SSD techniques with a pinpoint chamber for 6 MV beams at a depth of five and ten centimeters.

Field size (cm^2)	5 cm SAD	5 cm SSD	10 cm SSD	10 cm SAD
3 X 3	0.881	0.884	0.830	0.832
5 X 5	0.926	0.931	0.895	0.892
7 X 7	0.960	0.963	0.943	0.939
10 X 10	1.000	1.000	1.000	1.000
15 X 15	1.043	1.041	1.061	1.061
20 X 20	1.068	1.066	1.101	1.104
30 X 30	1.102	1.106	1.154	1.158
40 X 40	1.128	1.131	1.198	1.192

MV: Megavoltage, SAD: Source to axis distance, SSD: Source to surface distance.

Table 7. Output factors determined using the SAD and SSD techniques using a semi-flex chamber for six MV beams at a depth of five and ten centimeters.

Field size (cm^2)	5 cm SAD	5 cm SSD	10 cm SSD	10 cm SAD
3 X 3	0.879	0.880	0.832	0.833
5 X 5	0.928	0.927	0.894	0.895
7 X 7	0.963	0.963	0.945	0.945
10 X 10	1.000	1.000	1.000	1.000
15 X 15	1.039	1.039	1.060	1.062
20 X 20	1.067	1.066	1.101	1.105
30 X 30	1.105	1.104	1.156	1.162
40 X 40	1.123	1.121	1.184	1.191

MV: Megavoltage, SAD: Source to axis distance, SSD: Source to surface distance.

In comparison to small field sizes, larger field sizes demonstrated the greatest difference across all chambers.

The smallest output factor and the highest output factor of the large field size (40 × 40 cm^2) were noted in table 1 and found that the smallest output factors were measured at 5 cm SAD and the highest output factors measured at 10 cm SSD. The TPS was therefore modeled using output factors of 5 cm SAD and 10 cm SSD. The validation tests were carried out with different SSDs other than the SSD used for beam data generation for different field sizes (Symmetrical and Asymmetrical). We could not find much difference in the validation part. The small field plans were optimized with 5 cm SAD output factors, and another plan was calculated by merely changing the model with SSD output factors. No change in optimization was done. Both the plans were transferred to the phantom of separation 15 cm, and point dose measurements were performed.

The measured point dose variation from calculated and monitored unit differences was noted for ten small and large fields. A variation in measured dose from TPS calculated ranges from 0 to -2.7 % was noted for small field plans calculated with the SAD technique and -0.22 to-2.31 % for plans calculated with the SSD technique. For large fields, it ranges from -0.89 to 0.8 % for SAD and -0.6 to 0.64 % for the SSD technique. The MU was noted for the above plans.

DISCUSSION

The scatter factors measured at 10 cm depth in the SAD setup were close (0.13 %) to Shande *et al.* (17) measurements for small field size (3×3 cm^2) and -0.2 % variation with Beyer *et al.* (18), who performed the output factor measurements at 5 cm depth in isocentric setup. The variation of the output factor of Beyer *et al.* (18) for Shende *et al.* (17) was found to be -5.14 % which can be because of the setup. The variation of output factor at a depth of 5 cm and 10 cm in the isocentric setup of this study was also -5.5 %.

A study by Azimi *et al.* (11) discovered a 2.9% variation in dose measurements for +5.0 % change in output factor, 5.4 % for +10 %, 0.8 % for −5.0 %, 3.6 % for −10 % change in output factor in Elekta units whereas for Varian units no variations were found. In the present study, we found a variation of -6.3 % to 5.2 % in output factor, a maximum variation of 2.3 % in dose measurements for small-sized tumors, and a maximum variation of 0.89 % for large-sized tumors.

In their study, Shamsi *et al.* (4) measured small field output factors with SSD at 90cm and chambers at 10cm. The output factors measured with these setup using CC01 was in close agreement with our values with a Pinpoint chamber at 10cm depth with SSD 90cm.

Sedani *et al.* (10), Azimi *et al.* (11), and Mamesa *et al.* (14) in their study found that the corrected output factors in TPS were found to be significant for very small volume stereotaxy plans with Eclipse TPS. The MU difference was hardly found in both small and large fields. When calculating the P value, for 3DCRT cases, it came to 0.39, for IMRT 0.16, for small field VMAT plans 0.45, and for large field VMAT, it came to 0.55, which means that this is insignificant. For routine treatments, output factors measured with the SAD or SSD technique do not affect the plan.

The small field output factors were high for 5cm depth measurements compared to 10cm, whereas for larger field size, it was the other way, which means 10cm depth output factors were high compared to output factors measured at 5 cm depth. When comparing the output factors measured in all set up for small field size (3 × 3 cm^2), the farmer chamber showed a lower output factor when compared to Semiflex and Pinpoint chamber. At 5 cm SAD setup output factor for 3 × 3 cm^2 shows a more significant difference between a farmer and pinpoint chamber compared to another setup. This is because the chamber is closer to the source for the above setup. Because there is no lateral electronic equilibrium in tiny fields with farmer chambers, there is under-dosing, but output factors calculated at a depth of 10 cm revealed less variance. This may be because the field size at 5 and 10 cm depth, even in SSD or SAD, will differ by a factor of 0.95.

Hence a 5 × 5 cm^2 at 100 cm is 5.25 × 5.25 cm^2 at 105 cm and 5.5 × 5.5 cm^2 at 110 cm from source, thereby achieving the lateral equilibrium. Hence, the out factor of small field sizes is almost identical for 10 cm depth output factors with pinpoint and Semiflex chambers. When compared with different energies, it was found that the difference in 5 cm depth and 10 cm depth measured output factors decreases with energy. The same results were obtained for FFF photon beams. Apart from these, we have found a dip in output factors measured with farmer chambers for larger field sizes than Pinpoint and Semiflex chambers.

CONCLUSION

The percentage difference in output factors at two depths was more prominent for low energy beams (6 MV) than higher energy beams. The change in output factors does not produce much significant difference in dose calculation and delivery for 3DCRT, IMRT, and VMAT plans. Hence it is better to take the depth of measurement as 10 cm even though the recommendation for depth of measurement of output factor for low energy is 5 cm. Though the significance of different setup output factors is less in treatment planning, it is better to take measurements at 100 cm SSD and 10 cm depth to increase the lateral equilibrium for small fields and low energy beams.

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