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Comparison between measured tissue phantom ratio values and calculated from percent depth doses with and without peak scatter correction factor in a 6 MV beam

Ganesh Narayanasamy, Wilbert Cruz, Niko Papanikolaou, Sotirios Stathakis

Department of Radiation Oncology, University of Texas Health Science Center San Antonio, San Antonio, USA

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Technical Report

Abstract

The purpose of this study is to examine the accuracy of calculated tissue phantom ratio (TPR) data with measured TPR values of a 6MV photon beam. TPR was calculated from the measured percent depth dose (PDD) values using 2 methods – with and without correcting for the differences in peak scatter fraction (PSF). Mean error less than 1% was observed between the measured and calculated TPR values with the PSF correction, for all clinically relevant field sizes and depths. When not accounting for the PSF correction, mean difference between the measured and calculated TPR values was larger than 1% for square field sizes ranging from 3 cm to 10 cm.

Keywords: TPR; PDD; PSF; Dosimetry; Radiation Measurements

Introduction

There are several different radiation dosimetry quantities that are in use – percentage depth dose (PDD), tissue-phantom ratio (TPR), tissue maximum ratio (TMR), tissue air ratio (TAR), backscatter factor (BSF).[1] Even though all these quantities can be determined empirically, most of the tabulated data have been calculated from the measured PDD of open field central axis (CAX).[2] While it is easier to measure radiation beam data in the form of PDD, it is often convenient to calculate dose per monitor unit (MU) using isocentric beam data based on TPR values. The PDD values are measured at a fixed source to surface distance (SSD) along the CAX and TPR at a fixed source to axis distance (SAD). Calculation of TPR values from the measured PDD data involves inverse square factor and possibly, the peak scatter factor (PSF) correction. PSF or phantom scatter factor (denoted as S_p) is defined as the ratio of absorbed dose to water at the depth of dose maximum to the absorbed dose in free air at the same location for a given radiation beam.

The accuracy of the dosimetric quantities including PDD, TPR, TMR, TAR and BSF could affect the MU calculation.[3] Knowledge of the dependence of these quantities on various parameters including energy, field size, depth, and scatter is essential in accurate determination of absorbed dose and MU.[4] Several Monte Carlo studies have investigated the variation of these dosimetric quantities very effectively.[5, 6, 7] Yang, *et al.* proposed a method to separate CAX dose into primary, scatter and surface dose which lead to 3.3% difference between the measured TPR and calculated TPR values beyond the depth of maximum dose (dmax).[8] A few analytical models were proposed for extrapolation of TPR values to a wide range of field sizes and depths.[9, 10] Commissioning of a treatment planning system (TPS) depends on the accuracy of beam data (eg., PDD, TPR, profile scans, output factors).[11]

While various models have been proposed in the literature for estimation of TPR, TMR, TAR and BSF from the measured values of PDD, the predicted values of these quantities have to be verified by direct measurement. In this study, TPR data was measured on a clinical 6MV photon beam and compared against the TPR values calculated from the measured PDD data using inverse square factor with and without the PSF correction.

Methods and Materials

All measurements were made on a 600 Series linear accelerator (Varian Medical Systems, Palo Alto, CA) commissioned with 6MV photon beam. Measurements were made using a PTW MP3-M water tank (PTW, Freiburg, Germany) with a scanning range of 50 cm × 50 cm × 40 cm. PDD and TPR measurements were made along the CAX using Semiflex (31010) chambers (PTW, Freiburg, Germany) of 0.125 cc active volume for both ionization field and reference. PDD

Corresponding author: Ganesh Narayanasamy; Department of Radiation Oncology, University of Texas Health Science Center San Antonio, San Antonio, USA.

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data was measured at a source-to-surface distance (SSD) of 100 cm for 7 square field sizes – 3 cm, 5 cm, 10 cm, 15 cm, 20 cm, 25 cm and 30 cm. The TPR values were measured by continuous water draining method with ionization chamber static at source-to-detector distance (SDD) of 100 cm for depths up to 22 cm for the above mentioned fields.

The gantry was set to upright position initially and then leveled using spirit level to ensure correct alignment. The water tank is set to SSD of 100 cm and the moving mechanism (arms) is leveled to the crosshair. The ion chamber was positioned using a TRUFIX® detector positioning system (PTW, Freiburg, Germany) at the effective point of measurement. The centering of the chamber along the CAX of the beam was verified by the radiation center check, which checks the symmetry of the in-plane and cross-plane profiles at 2 different depths (usually at 5 cm and 20 cm). Once the radiation center check is performed, the detector positioning can be verified to be along the CAX to within a fraction of a millimeter, which is critical especially for small fields. PDD data is measured along the CAX of the open photon beam. For TPR measurement, the water tank is raised such that the SSD is within a range of 70 cm to 80 cm. The tank leveling is again verified. The draining process is calibrated by a water sensor which is mounted to the arm that estimates the water flow rate at 2 different water levels.

Data processing and analysis was performed using PTW's MEPHYSTO mc² Navigator software (PTW, Freiburg, Germany). The data was smoothed by a least-squares algorithm, interpolated to 1mm spacing and normalized to 100% by the value at the depth of maximum dose (dmax). Comparison between the measured and calculated TPR values was performed using a 2-tailed paired Student's T-test. The absence of null hypothesis is supported by a p-value < 0.05.

The TMR of a given field size r_d at depth d is calculated from PDD using[12]:

$$TMR(r_d, d) = \frac{PDD(r_s, d, SSD)}{100}\left(\frac{100+d}{100+d_{max}}\right)^2 \frac{S_p(r_{dmax})}{S_p(r_d)}$$

where, r_d is the field size at the depth d, r_s is the field size projected at the surface of the phantom, and $S_p(r_{dmax})$ is the phantom scatter factor for field size r_{dmax} is defined as:

$$S_p(r_{dmax}) = \frac{S_{cp}(r_{dmax})}{S_c(r_d)}$$

where, S_{cp} is the output factor and S_c is the in-air collimator scatter factor.

The field sizes r_{dmax} and r_d are related by this equation based on geometry:

$$r_{dmax} = \frac{(100 - d + dmax)}{100} r_d$$

Results

In this study, TPR values were measured along the CAX of 6MV photon beam of 7 field sizes mentioned earlier up to a maximum depth of 22 cm. A comparison study was performed between the 3 methods - (a) measured TPR data; (b) TPR values calculated from PDD without PSF correction; and (c) TPR values calculated from PDD with PSF correction. The parameters that characterize the TPR curve including the dmax, TPR at the surface defined at 0.5mm depth (TPRs), TPR at depths of 5 cm, 10 cm and 20 cm (TPR5, TPR10 and TPR20, respectively) are tabulated for the 7 square field sizes in **Table 1**.

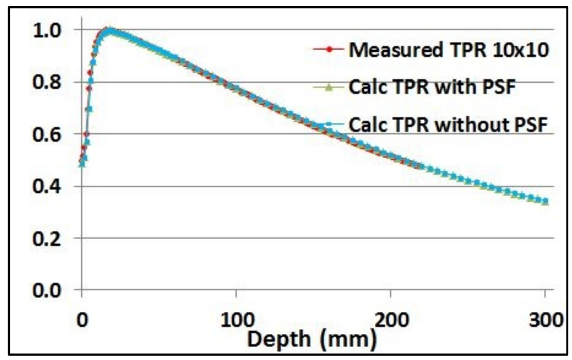

FIG. 1: Measured TPR data and TPR values calculated from PDD values along the central axis of a 10 cm × 10 cm, 6MV photon beam.

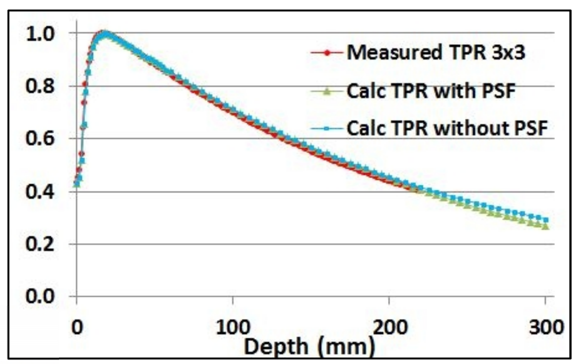

FIG. 2: Measured TPR data and TPR values calculated from PDD values along the central axis of a 3cm × 3cm, 6MV photon beam.

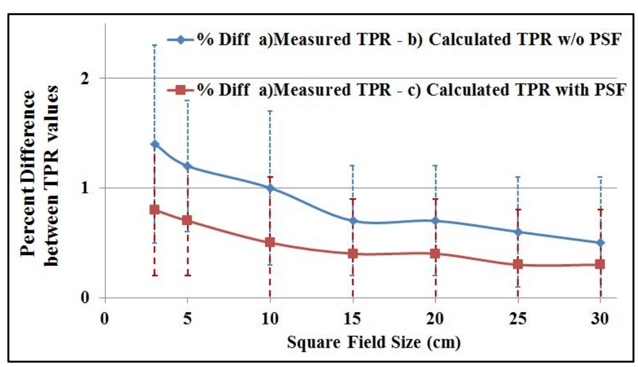

FIG. 3: Percentage difference between TPR values a) - b) and a) - c) increases with decreasing field sizes with correlation coefficient of = 0.95 and 0.93, respectively.

TABLE 1: Comparison of values of dmax, TPR at the surface (TPRs), at depths of 5 cm, 10 cm, and 20 cm for the 3 methods - a) Measured TPR; b) TPR calculated from PDD without PSF correction; and c) TPR calculated with PSF correction.

Square field size (cm)	Property	a) Measured TPR	b) Calculated TPR without PSF	c) Calculated TPR with PSF
3	Dmax(mm)	17	15	16
	TPRs	0.45	0.42	0.45
	TPR5	0.88	0.91	0.89
	TPR10	0.70	0.73	0.70
	TPR20	0.44	0.46	0.45
5	Dmax(mm)	17	16	16.5
	TPRs	0.46	0.43	0.46
	TPR5	0.90	0.93	0.90
	TPR10	0.73	0.75	0.74
	TPR20	0.47	0.48	0.47
10	Dmax(mm)	16	16	16
	TPRs	0.51	0.49	0.51
	TPR5	0.92	0.94	0.92
	TPR10	0.77	0.79	0.77
	TPR20	0.51	0.53	0.52
15	Dmax(mm)	17	15	16
	TPRs	0.55	0.53	0.55
	TPR5	0.93	0.95	0.94
	TPR10	0.80	0.82	0.80
	TPR20	0.56	0.57	0.56
20	Dmax(mm)	17	16	16
	TPRs	0.59	0.57	0.58
	TPR5	0.94	0.92	0.94
	TPR10	0.81	0.83	0.82
	TPR20	0.58	0.59	0.58
25	Dmax(mm)	15	15	15
	TPRs	0.62	0.60	0.61
	TPR5	0.94	0.94	0.94
	TPR10	0.82	0.83	0.83
	TPR20	0.60	0.60	0.60
30	Dmax(mm)	15	15	15
	TPRs	0.65	0.64	0.64
	TPR5	0.94	0.94	0.94
	TPR10	0.83	0.83	0.83
	TPR20	0.61	0.62	0.61

Shown in **Figure 1** is the plot of TPR values from the 3 methods for a 10 cm × 10 cm field size. Note that the 3 sets of TPR values agree with one another ≤1%. However, the deviation between methods a) and b) became larger than 1% for a 3 cm × 3 cm field especially with increasing depths, as shown in **Figure 2**. When averaged over the entire depth of acquisition, the mean percentage difference in TPR values between the methods a) and b) range from 0.5% up to 1.4% depending on the field size. The mean differences in TPR values between methods a) and c) range from 0.3% up to 0.8%. The percent difference in the TPR values between methods a) & b) as well as that between methods a) and c) for the 7 square field sizes are tabulated in **Table 2** as mean ± standard deviation. 2-tailed paired Student's T-test did not reveal the presence of significant differences between TPR values from methods a), b) and c) with a p-value > 0.05. However, a trend is seen in increasing mean differences with decreasing field sizes, as depicted in **Figure 3**. The correlation coefficient between the difference in TPR values from methods a) and b) with the field size is $R^2 = -0.95$. The corresponding correlation coefficient between the difference in TPR values from methods a) and c) with the field size is $R^2 = -0.93$.

TABLE 2: Percent difference in the TPR values between methods a) and b) and between methods a) and c) for the 7 square field sizes measured, represented as mean ± standard deviation.

Square field size (cm)	% Difference: a) - b)	% Difference: a) - c)
3	1.4% ± 0.9%	0.8% ± 0.6%
5	1.2% ± 0.6%	0.7% ± 0.5%
10	1.0% ± 0.7%	0.5% ± 0.6%
15	0.7% ± 0.5%	0.4% ± 0.5%
20	0.7% ± 0.5%	0.4% ± 0.5%
25	0.6% ± 0.5%	0.3% ± 0.5%
30	0.5% ± 0.6%	0.3% ± 0.5%

Discussion

Higher accuracy in the beam data would lead to more accurate beam modeling in the treatment planning system.[13] It is of vital importance that the collected data have the highest accuracy to avoid dosimetric errors that may lead to poor treatment outcome. In this study, the TPR values calculated from PDD with PSF correction agree with the TPR values measured to within 1% and the dmax values are within 1mm of each other.

The deviation between measured and calculated TPR values without PSF correction is larger in magnitude than that calculated with the PSF correction for all the field sizes and depths measured. In fact, the differences between measured and calculated TPR values without PSF correction are larger than 1% for field sizes smaller than 10 cm × 10 cm. When averaged over the depth of measurement, the mean difference between measured and calculated TPR values has a strong negative correlation with the square field size between the range 3 cm and 30 cm.

Some of the deviations between the measured and calculated TPR values could be explained from the computation of S_p values from S_{cp} and S_c. S_c suffers from electron contamination that varies substantially with distance from the source. A mini-phantom with sufficient lateral and longitudinal thickness that provides charge particle equilibrium is recommended, per TG-74.[14] The use of S_c and S_p values defined at a reference depth of 10 cm is recommended.[15] PSF also suffers from a SSD dependence that was not considered in the British Journal of Radiology (Supplement 25), as mentioned in Bedford *et al.*[16]

TPR measurement of very small fields or different photon energy is beyond the scope of this investigation. Challenges with small field dosimetry include lack of charge particle equilibrium, partial volume averaging, and positioning accuracy. Few alternate methods were suggested in the literature for measurement of TMR values of small fields using a small volume dosimeter with accurate positioning accuracy along the CAX of the beam.[17, 18, 19]

Conclusion

Calculation of TPR data from PDD with PSF correction has been shown to have good agreement with directly measured data. The measured TPR or that calculated from PDD data with PSF correction would both be suitable for clinical use for all clinically relevant depths and field sizes. The mean difference between measured and calculated TPR values averaged over depth shows a strong negative correlation with the field size ranging from 3 cm × 3 cm to 30 cm × 30 cm.

Conflict of interest

The authors declare that they have no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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