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Analysis of Tissue Phantom Ratio of the Megavoltage Photon Beams

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ABSTRACT

Iso-centric beam data, phantom tissue ratios (TPR) are a dosimetric quantity commonly used to describe the change in dose with depth in tissue. Measurement of this is time-consuming and has the possibility of lose the consistency. The value of this quantity of any filed size in any depth is possible to calculate conveniently by the newly developed formula using only percentage depth dose (PDD) data of two fields. PDD for square fields ranging from 2 to 30 cm and various depths in increment of 0.4 cm up to maximum 30 cm have been measured in water at a fixed source surface distance (SSD) of 90 cm for 4, 6 and 15 MV photon beams in Ahsania Mission Cancer & General Hospital (AMCGH), Dhaka, Bangladesh. TPR values calculating for these energies of the same field sizes, depths and SSD by using the developed formula compared with those determined from the measured PDD data using a standard formula and had the good agreement. Mean error less than 1% observed between these TPR values.

Key words: TPR, PDD, Dosimetry, Photon beam and Radiation Measurement

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INTRODUCTION

There are several radiation dosimetry quantities such as percentage depth dose (PDD), tissue phantom ratio (TPR), tissue maximum ratio (TMR), tissue air ratio (TAR) and backscatter factor (BSF) (Purdy J A 1977, Rahman M. A. *et al* 2016). TPR is being used to describe the change in dose with depth in tissue. Data for different field sizes of this quantity are often used as reference data check determined within an individual radiotherapy department (Neil Richmond and Robert Brackenridge 2014).These data are usually tabulated as a function of depth and field size at the iso-centre for a given quality index. Most of the tabulated data are calculated from measured PDD of open field central axis even though all these dosimetry quantities can be determined empirically (Bjärngard BE, Zhu TC, Ceberg C 1996). It is often convenient to calculate dose per monitor unit using iso-centric beam data based on TPR values than the measured radiation beam data in the form of PDD.

TPR is formed by the ratio of two doses:

$TPR = D_d / D_{ref}$ ………(1)

where D_{ref} is the dose at a specific reference point on the central axis at a fixed reference depth, d_{ref}, in water and D_d is the dose measured at an arbitrary depth where TPR value wants to be known. The reference point is often defined at 100 cm from the source which is typically the source to axis distance (SAD) and d_{ref} can be chosen at any depth but 10 cm is common.

Although TPR data can be measured directly to avoid uncertainties associated with deriving them from percentage depth dose but in practice, they are generally converted from PDD curves because it is convenient to measure PDD at a fixed source to surface distance (Das I J *et al.* 1996, Sharma S C *et al.* 2007). This is because many water tank systems do not have the ability to change accurately the depth of water while leaving the chamber at a fixed SSD.

Furthermore, manually changing the depth of water for many depths and field sizes is very time-consuming and often unpractical (Alam M J *et al.* 2007, Narayanasamy G *et al.* 2015].

The accuracy of TPR could affect the monitor unit (MU) calculation (Bjarngard BE, Bar-Deroma R, Corrao A 1994). Knowledge of the dependence of the quantity on various parameters including energy, field size and depth is essential to provide accurate dose and MU (G. X Ding and Rob Krauss 2013). Commissioning of a treatment planning system (TPS) depends on the accuracy of the beam data of TPR (Bedford JL *et al.* 2003). Data for different field sizes and depths of the quantity of 4, 6 and 15 MV photons have been calculated using the newly developed formula (Alam M J *et al.* 2007). The advantage of the formula is that the value of the quantity of any field size and any depth can be obtained easily by using measured PDD values of two fields. TPR values obtained from the equation (1) compared with those calculated using the newly developed formula in this work.

Material and Method

It was intended to analysis the dosimetry quantity Tissue-Phantom Ratio of high energy photon beams of diverse range for treatment of cancer patient. This quantity usually calculated from the measured percentage depth dose data. The doses were measured in water as it is always assumed to be the better phantom for being very close to human due to its density and number of electrons per gram and universally available with reproducible radiation properties.

Measurements for PDD were made using a PTW water tank using Mephisto mc^2 software version 1.3 on an Elekta Linear Accelerator aligned to the central axis of the radiation beam. Detector alignment was achieved by scanning cross plane and in plane profiles for each field size at 10 cm deep, 90 cm source-surface distance (SSD). The data recorded from the water surface to 30 cm deep in 0.4 increments for square collimator setting from 30 x 30 cm^2 to 2 x 2 cm^2 for 4, 6, and 15 MV photon beams. TPRs were determined by using these measured PDDs in the equation (1). PDD values of two field sizes 10 x 10 cm^2 and 30 x 30 cm^2 were used in the developed formula (Alam M J *et al.* 2007) to calculate TPRs for 7 square fields 2, 5, 10.15, 20, 25 and 30 cm for depths for the same photon beams up to 30 cm in 0.4 increments. Each TPR data normalized at a depth of 10 cm.

Result and Discussion

The values of tissue-phantom ratio (TPR) calculated for three photon energies, 4, 6, and 15 MV of 7 field sizes ranging from 2 cm to 30 cm and various depths up to 30 cm with the increment of 0.4 cm along the central beam axis using a newly developed formula (Alam M J *et al.* 2007) where PDD values of two field sizes used. A comparison study performed between these calculated values normalized to 10 cm depth and TPR values determined from measured PDD data using the standard equation (1). The parameters that characterize the TPR curve including the d_{max} and surface were tabulated for the seven square field sizes in the table 1 to 6 for the energies.

Table 1: TPRs calculated from the developed formula in water at SSD 90 cm for 4 MV photon beam.

Field Size(cm^2)	5x5	10x10	15x15	20x20	25x25	30x30
Depth in (cm)	TPR	TPR	TPR	TPR	TPR	TPR
0	0.741	0.765	0.787	0.808	0.831	0.850
1.2	1.367	1.342	1.315	1.289	1.266	1.242
2	1.356	1.330	1.305	1.279	1.256	1.233
4	1.274	1.256	1.236	1.218	1.200	1.183
6	1.186	1.174	1.161	1.148	1.137	1.125
8	1.093	1.087	1.081	1.0754	1.071	1.064
10	1	1	1	1	1	1
12	0.912	0.918	0.922	0.927	0.931	0.935
14	0.832	0.8425	0.850	0.858741	0.868	0.874
16	0.755	0.768	0.780	0.791	0.802	0.812
18	0.686	0.703	0.716	0.730	0.743	0.756
20	0.626	0.641	0.657	0.671	0.686	0.700
22	0.565	0.583	0.600	0.616	0.633	0.648
24	0.514	0.534	0.550	0.566	0.583	0.598
26	0.468	0.487	0.504	0.520	0.537	0.552
28	0.427	0.445	0.4627	0.4783	0.494	0.509
30	0.3857	0.404	0.422	0.439	0.456	0.470

Table 2: TPRs determined from measured PDD using equation (1) in water at SSD 90 cm for 4 MV photon beam

Field Size(cm^2)	5x5	10x10	15x15	20x20	25x25	30x30
Depth in (cm)	TPR	TPR	TPR	TPR	TPR	TPR
0	0.931	0.940	0.950	0.987	1.010	1.036
1.2	1.712	1.605	1.547	1.515	1.492	1.474
2	1.667	1.565	1.510	1.478	1.455	1.439
4	1.486	1.415	1.377	1.35	1.335	1.324
6	1.308	1.269	1.244	1.228	1.217	1.209
8	1.143	1.130	1.119	1.110	1.105	1.103
10	1	1	1	1	1	1
12	0.873	0.884	0.894	0.9	0.902	0.904
14	0.7616	0.781	0.795	0.804	0.810	0.817
16	0.664	0.688	0.707	0.719	0.729	0.735
18	0.580	0.608	0.628	0.643	0.655	0.663
20	0.510	0.537	0.558	0.574	0.586	0.597
22	0.445	0.473	0.496	0.515	0.526	0.5383
24	0.392123	0.418	0.442	0.459	0.473	0.4837
26	0.344	0.370	0.3931	0.410	0.423	0.435
28	0.303	0.329	0.349	0.366	0.379	0.390
30	0.267	0.290	0.311	0.327	0.340	0.352

Table 3: TPRs calculated from the developed formula in water at SSD 90 cm for 6 MV photon beam

Field Size(cm^2)	2x2	5x5	10x10	15x15	20x20	25x25	30x30
Depth in cm	**TPR**	**TPR**	**TPR**	**TPR**	**TPR**	**TPR**	**TPR**
0	0.688	0.679	0.709	0.760	0.802	0.844	0.875
1.6	1.291	1.279	1.261	1.244	1.228	1.212	1.195
2	1.298	1.284	1.265	1.247	1.229	1.212	1.194
4	1.236	1.224	1.210	1.195	1.182	1.168188	1.152
6	1.159	1.151	1.142	1.132	1.124	1.114	1.105
8	1.079	1.074	1.070	1.066	1.063	1.059	1.055
10	1	1	1	1	1	1	1
12	0.925	0.927	0.930	0.935	0.939	0.942	0.946
14	0.852	0.856	0.864	0.871	0.879	0.886	0.892
16	0.786111	0.792	0.801	0.812	0.821	0.831	0.840
18	0.725	0.731	0.744	0.756	0.767	0.779	0.789
20	0.668	0.675	0.689	0.702	0.715	0.727	0.739
22	0.615	0.624	0.639	0.653	0.667	0.680	0.692
24	0.566	0.574	0.590	0.605	0.620	0.634	0.647
26	0.525	0.533	0.548	0.563	0.578	0.591	0.605
28	0.481	0.491	0.506	0.522	0.536	0.551	0.565
30	0.444	0.453	0.469	0.484	0.499	0.513	0.526

Table 4: TPRs determined from measured PDD using equation (1) in water at SSD 90 cm for 6 MV photon beam

Field Size(cm^2)	2x2	5x5	10x10	15x15	20x20	25x25	30x30
Depth in cm	**TPR**	**TPR**	**TPR**	**TPR**	**TPR**	**TPR**	**TPR**
0	0.637	0.665	0.711	0.756	0.799	0.8420	0.883
1.6	1.538	1.525	1.503	1.483	1.463	1.443	1.424
2	1.533	1.519	1.496	1.474	1.452	1.431	1.410
4	1.397	1.386	1.369	1.353	1.337	1.321	1.306
6	1.256	1.250	1.239	1.229	1.219	1.209	1.199
8	1.122	1.119	1.115	1.111	1.106	1.102	1.098
10	1	1	1	1	1	1	1
12	0.888	0.891	0.894	0.898	0.902	0.906	0.909
14	0.788	0.792	0.799	0.806	0.812	0.818	0.825
16	0.699	0.705	0.714	0.723	0.731	0.739	0.748
18	0.621	0.627	0.638	0.648	0.658	0.667	0.677
20	0.552	0.558	0.569	0.580	0.591	0.601	0.611
22	0.490	0.497	0.509	0.520	0.531	0.542	0.552
24	0.435	0.442	0.454	0.466	0.477	0.487	0.498
26	0.389	0.396	0.407	0.418	0.429	0.439	0.449
28	0.345	0.352	0.363	0.374	0.385	0.395	0.406
30	0.308	0.315	0.326	0.336	0.346	0.356	0.366

Table 5: TPRs calculated from the developed formula in water at 90 cm SSD for15 MV photon beam

Field Sizes(cm^2)	2x2	5x5	10x10	15x15	20x20	25x25	30x30
Depth in cm	TPR	TPR	TPR	TPR	TPR	TPR	TPR
0	0.354	0.357	0.454	0.515	0.600	0.649	0.691
1.2	0.932	0.942	0.957	0.973	0.990	1.007	1.023
2	1.100	1.101	1.100	1.101	1.103	1.104	1.105
2.8	1.390	1.349	1.329	1.317	1.313	1.314	1.307
4	1.159	1.154	1.145	1.137	1.129	1.122	1.114
6	1.110	1.106	1.099	1.094	1.089	1.084	1.079
8	1.056	1.055	1.051	1.047	1.045	1.042	1.040
10	1	1	1	1	1	1	1
12	0.948	0.949	0.950	0.953	0.954	0.957	0.959
14	0.894	0.897	0.901	0.905	0.910	0.914	0.919
16	0.846	0.849	0.854	0.861	0.867	0.872	0.879
18	0.795	0.800	0.807	0.815	0.823	0.831	0.839
20	0.753	0.758	0.765	0.775	0.784	0.793	0.801
22	0.708	0.714	0.723	0.733	0.743	0.752	0.763
24	0.669	0.675	0.685	0.696	0.705	0.716	0.726
26	0.631	0.638	0.648	0.659	0.669	0.680	0.691
28	0.596	0.601	0.613	0.624	0.635	0.646	0.656
30	0.563	0.569	0.579	0.590	0.601	0.612	0.623

Table 6: TPRs determined from measured PDD using equation (1) in water at SSD 9 cm for 15 MV photon beam

Field Sizes(cm^2)	2x2	5x5	10x10	15x15	20x20	25x25	30x30
Depth in cm	TPR	TPR	TPR	TPR	TPR	TPR	TPR
0	0.354	0.357	0.454	0.515	0.600	0.649	0.691
1.2	1.183	1.113	1.151	1.172	1.211	1.224	1.228
2	1.368	1.303	1.300	1.300	1.308	1.308	1.303
2.8	1.390	1.349	1.329	1.317	1.313	1.307	1.300
4	1.340	1.321	1.295	1.277	1.270	1.262	1.256
6	1.221	1.211	1.192	1.181	1.176	1.172	1.167
8	1.105	1.101	1.094	1.086	1.085	1.084	1.079
10	1	1	1	1	1	1	1
12	0.905	0.908	0.914	0.918	0.920	0.923	0.924
14	0.820	0.824	0.835	0.841	0.848	0.851	0.853
16	0.744	0.748	0.763	0.772	0.779	0.784	0.788
18	0.675	0.680	0.695	0.707	0.717	0.722	0.726
20	0.614	0.618	0.636	0.649	0.659	0.666	0.671
22	0.559	0.562	0.581	0.595	0.606	0.613	0.619
24	0.509	0.512	0.531	0.546	0.558	0.566	0.571
26	0.4631	0.466	0.486	0.500	0.513	0.521	0.526
28	0.422	0.426	0.445	0.461	0.470	0.480	0.486
30	0.385	0.388	0.408	0.422	0.434	0.442	0.448

Fig.1: Distribution of Tissue-phantom ratios along cental axis for different quality photon beams in water

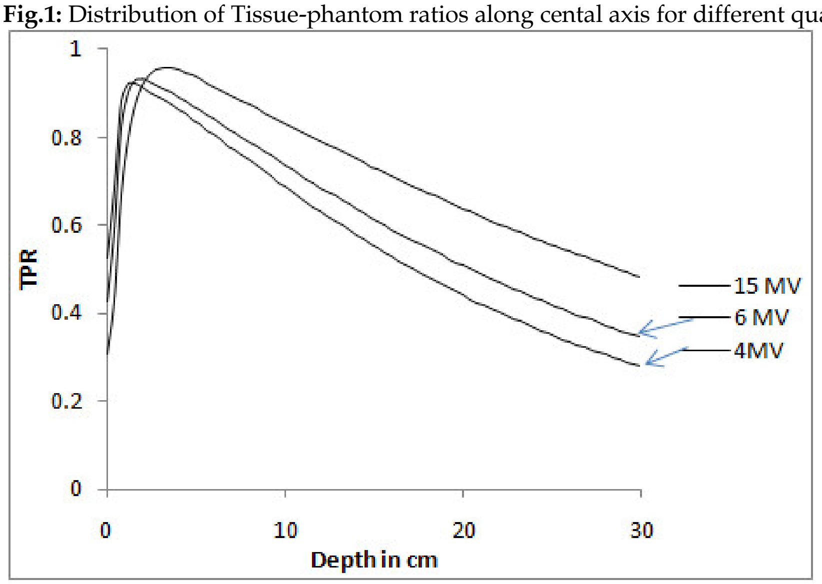


Figure 1 shows that TPR values depend on the depth and energy. It is seen that maximum TPR is not at the surface but at some depths. Beyond the depth of maximum value, it varies exponentially with the depth. The figure also indicates that for all energies it increases rapidly with first few centimeters and then gradually achieves its maximum value at the depth of peak dose. In the case of 4 MV photon beam it occurs at 1.2 cm. Similarly, maximum values occur at 1.6 cm and 2.8 cm, for 6 and 15 MV photon beams respectively. Higher energy beams have grater penetrating power thus deliver a high depth dose. As a result, the peak value of TPR increases with the energy.

4 MV Photon Beams

Fig.2: Comparison of TPRs along the central beam axis in increment of 0.4 cm up to maximum 30 cm of various square field sizes of 4 MV photon beam

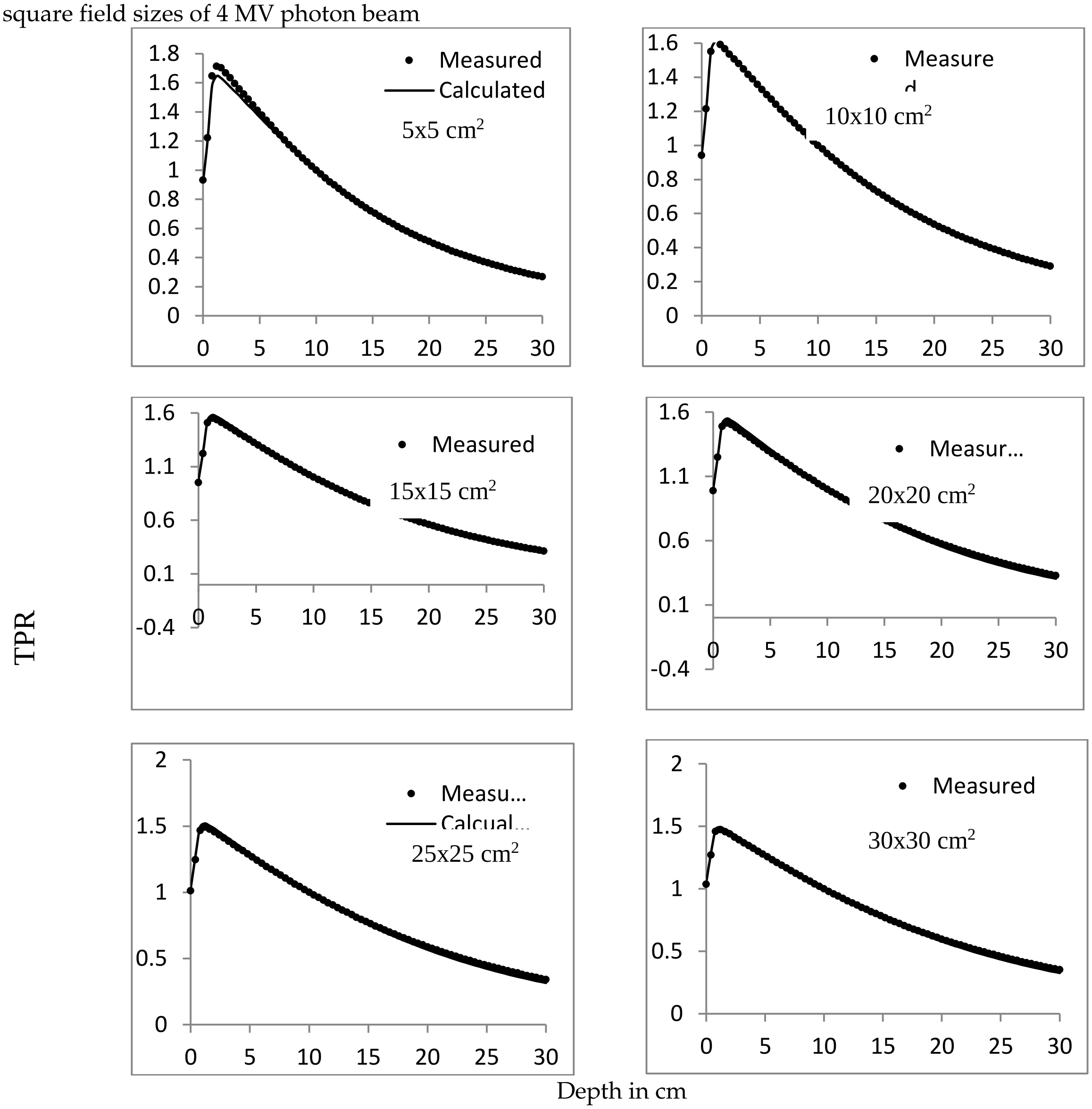
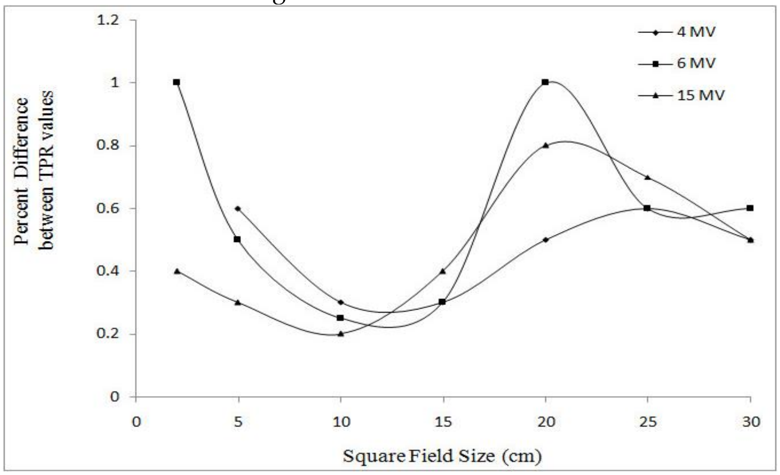


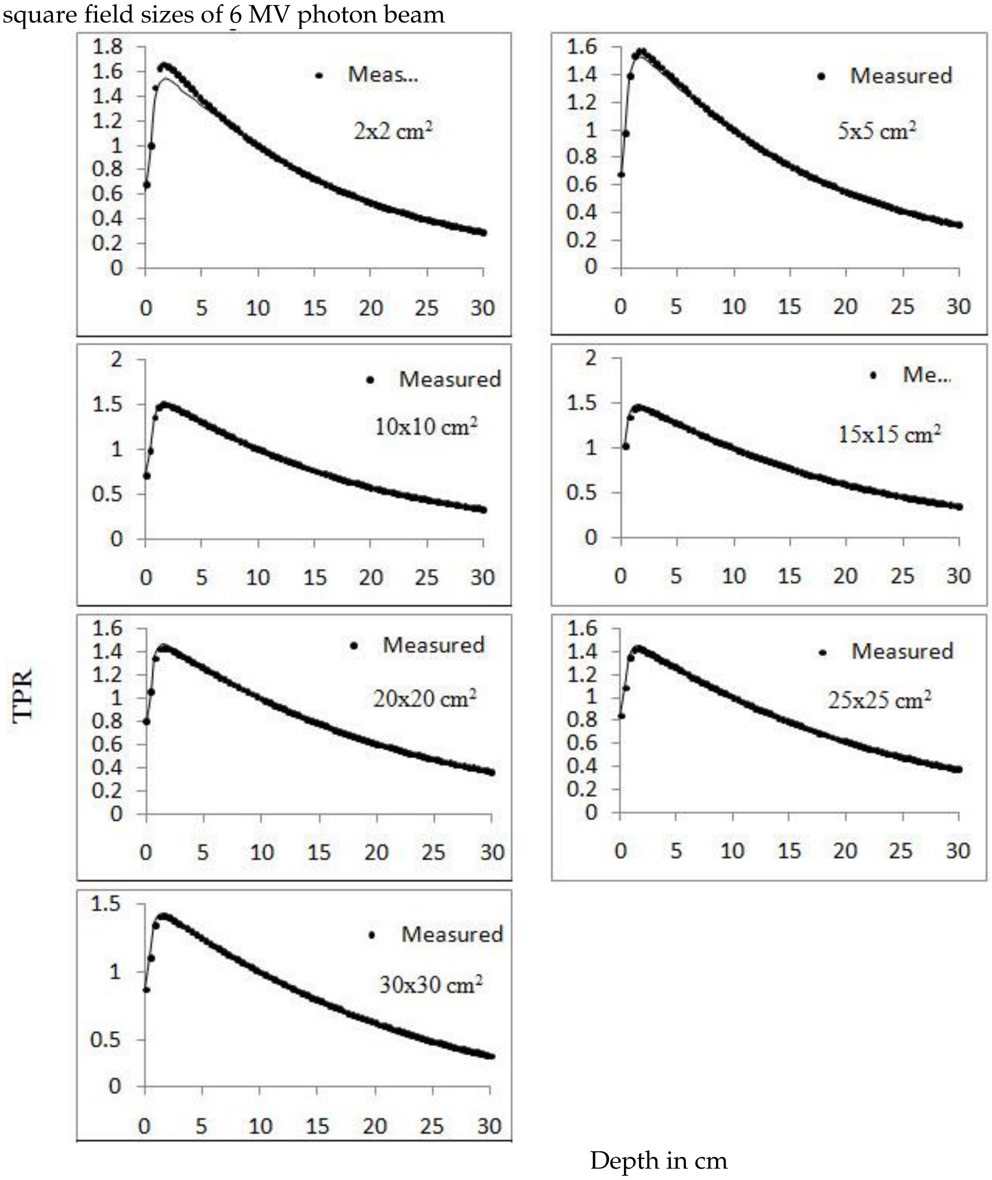
Figure 2 presents the comparison of TPR values of this energy obtained from both the formulas. The agreement is good for all depths and fields sizes and indicates that TPR values calculated from the developed formula are comparable to those determined from the measured PDD data using the equation (1). Thus, it has the potential to reduce greatly the difficulty and time required to obtain accurate TPR values than directly measuring TPRs. Some TPRs of shown in the figure 2 are listed in Tables 1 and 2 as a function of depth and field size. By comparing these tables, it can be seen that maximum difference occurs by 0.34 at 1.2 cm depth of the field size 5 x 5 cm^2 and lowest by 0.027 at 12 cm depth of the field size of 20 x 20 cm^2. When averaged over the entire depth of acquisition, the mean difference in TPR values are 0.6%, 0.3%, 0.5%, 0.6%, and 0.7% of the field sizes 5, 10, 15, 20, 25 and 30 cm^2 respectively. A trend is seen in the Fig.3.

Fig.3: Percent difference between TPR values with the increasing of field sizes. Decreasing mean difference first with field sizes then increasing but later decreases



6 MV Photon Beams

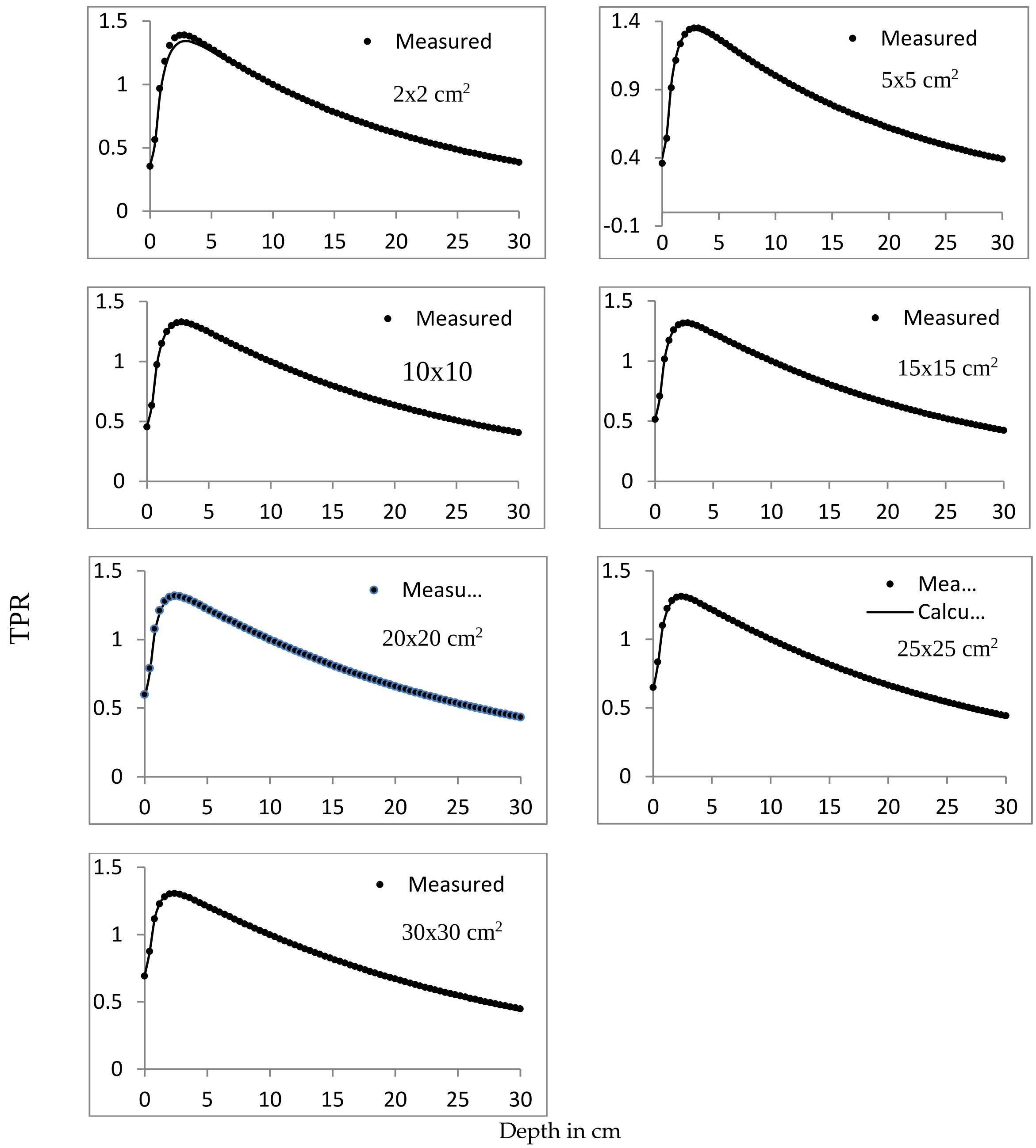
Fig.4: Comparison of TPRs along the central beam axis in increment of 0.4 cm up to maximum 30 cm of various square field sizes of 6 MV photon beam



The comparison between TPR values for this energy presented in the Fig.4. The agreement is good for all depths and fields sizes and indicates that TPR values calculated from the developed formula are comparable to those determined from the measured PDD data using the equation (1). Some TPR values of shown in the Fig. 4 are listed in tables 3 and 4 as a function depth and field size. By comparing these Tables, it can be seen that maximum difference occurs by 0.24 at 1.6 cm depth of field size 2x2 cm^2 and lowest by 0.035 at 12 cm depth of field size of 10 x10 cm^2. When averaged over the entire depth of acquisition, the mean difference in TPR values are 1%, 0.5%, 0.2%, 0.3%, 1%,0.6% and 0.5% of the field sizes 2, 5, 10, 15, 20, 25 and 30 cm^2 respectively. A trend is seen in the Fig.3 in decreasing mean difference first with field sizes then increasing but later decreases.

15 MV Photon Beams

Fig.5: Comparison of TPRs along the central beam axis in increment of 0.4 cm up to maximum 30 cm of various square field sizes of 15 MV photon beam



The comparison of the TPR values presented in the Fig.5 of this energy is in good agreement for all depths and fields sizes and shows both the data are comparable. Some TPR values of shown in the Fig.5 are listed in Tables 5 and 6 as a function depth and field size. By comparing these tables, it can be seen that maximum difference occurs by 0.25 at 1.2 cm depth of field size 2x2 cm^2 and lowest by 0.033 at 12 cm depth of field size of 20 x20 cm^2. When averaged over the entire depth of acquisition, the mean difference in TPR values are 0.5%, 0.3%, 0.2%, 0.4%, and 0.8%, 0.7% and 0.5% of the field sizes 2, 5, 10, 15, 20, 25 and 30 cm^2 respectively. A trend is seen in the Fig.3 in decreasing mean difference first with field sizes then increasing but later also decreases.

Conclusion

Calculation of TPR data for seven square field sizes from the developed formula using PDDs of two fields has been shown to have good agreement with those determined from the measured PDDs using a standard formula (1). The mean difference in TPR values averaged over the entire depth 0 to 30 cm is less than 1% and shows that these values obtained from the developed formula has the potential to reduce greatly the difficulty and time required to obtain accurate TPRs and would be suitable for clinical use for all clinically relevant depths and field sizes.

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