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Dosimetric characterization of large photon fields (Varian, Clinac 2100C, X-6 MV) by using standard measurement approach

Georgios APOSTOLIDIS[1]
Jovan STANKOVIĆ[2]
Ljiljana RADOŠEVIĆ-JELIĆ[3]

[1]1INTERDISCIPLINARY GRADUATE STUDIES IN MEDICAL PHYSICS, NOVI SAD, YUGOSLAVIA
[2]SCHOOL OF MEDICINE, INSTITUTE OF BIOPHYSICS, BELGRADE, YUGOSLAVIA
[3]INSTITUTE FOR ONCOLOGY AND RADIOLOGY OF SERBIA, BELGRADE, YUGOSLAVIA

The most optimal dosimetry model for the application of large photon fields (dimensions larger than 40x40 cm) at extended focus-phantom/patient distances has not been adopted yet. A method based on a "classical" approach, that helps establishing a database (PDD, output and OF, PSF, Sc and TMR parameters) is discussed. Large photon fields produced by a CLINAC 2100C, Varian, in the low energy mode (6 MV) were analyzed by application of absolute and relative radiation dosimetry, as well as, by comparison with calculated data. A good agreement between measured and calculated values of radiation parameters examined, at FFD=180 and 300 cm, was observed. Slight increase in discrepancy (about 10 percent) of the TMR at FFD=300 cm, for fields larger than 50x50 cm and at larger depths was observed by comparison of calculated and measured values. Discrepancies of outputs between measured and calculated values (calculated by the inverse square law) were less than 2 percent. Most of the dosimetric data obtained, points out the possibility of application of radiotherapy unit CLINAC 2100C (Varian) for therapies with large fields in given conditions.

KEY WORDS: *Whole-Body Irradiation; Radiotherapy Dosage; Radiotherapy; Radiometry*

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INTRODUCTION

Large fields (larger than 45x45 cm) can be applied in various radiotherapy methods such as total body irradiation (TBI) and half body irradiation (HBI), treatment of non-Hodgkin's lymphoma, Ewing's sarcoma, lymphosarcoma, neuroblastoma, etc. A special branch of radiation dosimetry has been developed in the field of radiotherapy when a large part of patient's body has to be irradiated with high-energy photon beams that might go beyond the edge of patient's body. Special characteristics of these fields cannot be determined by simple extrapolation of the results obtained for small fields (up to 40x40cm, FFD=100cm), and they often depend on technical-technological characteristics of the radiotherapy device itself (5,6,8,9) and even therapy room design. The most optimal model for application in clinical practice can be found by monitoring behavior of large fields in the increased focus-phantom distances (FFD), and by identifying the factors that determine radiation quality and quantity.

The determination of radiation parameters of large fields and beams is the basis for the application of these fields in radiotherapy. In this article a database (PDD, output and OF, PSF, Sc and TMR parameters) for large fields were established in purpose to be used for radiation treatment planning at the Institute for Oncology and Radiology of Serbia.

Address correspondence to:
Jovan Stanković Ph.D., Assoc. Prof., School of Medicine, Institute of Biophysics, Višegradska 26/Ii, 11000 Belgrade, Yugoslavia

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MATERIALS AND METHODS

The measurements were taken at the Institute for Oncology and Radiology of Serbia, on CLINAC 2100C, Varian, USA, radiotherapy unit. The lower energy photon beam (X-6 MV) was used with referential dose rate of 320 cGy/min. The energy of photon beam of 6 MeV is chosen due to it's possible clinical application (by positioning the patient primarily in AP and PA positions).

The thimble ionization chamber NE 2571A was used for absolute measurements and the accompanying electrometer 2570/A. Relative dosimetry measurements were taken by using MULTIDATA water phantom of 60x59x50 cm and RFA3 Therados water phantom of 50x50x50 cm. Two identical 9732-2 thimble ionization chambers were used with internal active volume of 0.125 cm and an electrometer 9754, both produced by PTW company.

Two groups of measurements were taken at different FFD. The first group of fields at FFD=180 cm was created in vertical position of the beam (directed towards the floor). The maximum field during the vertical position of the beam was limited to 70x70 cm which was compatible with FFD=180. The other group of fields was created in horizontal position of the beam at FFD=300 cm and the maximum field amounts to 120x120 cm, that is 170 cm diagonally. The largest tested square field was 80x80 cm. For the fields of 90x90 cm and larger, a discrepancy was observed because the electronic system of scan frame was in the field then.

All radiation parameters were firstly determined at FFD=100 cm (PDD, TMR, output, OF, Sc, PSF) for square fields with vertical position of the beam. The sizes of the field were 10x10, 15x15, 20x20, 25x25, 30 x 30, 35 x 35, and 40x40 cm. All tested parameters were compared with the nominal values of the British Radiology Institute (1,2). The data acquired at FFD=100 cm were standard values representing referential therapy conditions and are used for comparing the values obtained by measurements taken for the large fields.

All radiation parameters (PDD, TMR, OF) were determined at FFD=180 cm for the vertical position of the beam, The dimensions of the fields being: 30x30, 40x40, 50x50 and 60x40, 60x60, 70x70 cm. The results obtained were compared with PDD calculated values through the PDD conversion formula from one FFD to another (from 100 cm to 180 cm):

$$PDD[d, f_2, S] = PDD[d, f_1, S/F]\frac{PSF[S/F]}{PSF[S]}F_s^2 \quad (1)$$

where PDD (d, f_2, S) is a percentage depth dose at the d depth, at f_1, f_2 represent FKD_1 and FKD_2 respectively; S represents the size of the field at the surface (SxS), PSF(S) determines the contribution of the scattered radiation in the absorbed dose for certain size of the field SxS and certain FKD (1,2), while factor F is given by

$$F_s = \frac{f_f + d}{f_1 + d_m}\frac{f_2 + d_m}{f_2 + d} \quad (2)$$

and represents corresponding Mayneord's factor.

PDD, OF, Sc in the horizontal position of the beam for the same dimensions of the field were compared. In these measurements RFA3 water tank coupled with and the MULTIDATA system for air scanning (scan frame) (4), was used because this water-tank has a window for horizontal scanning (plastic foil tick less than 0.5mm). Assuming that quality of the beam for rectangular and quadratic fields is identical, the rectangular fields were approximated with the standard square fields using the empiric formula c=2ab/(a+b), where c represents sides of calculated square equivalent field, while a and b being the sides of a rectangular field (1-3).

All radiation parameters (PDD, TMR, OF and output) were determined for FFD=300 cm setting, following filed dimensions of: 30x30, 40x40, 50x50, 60x60 and 120x40, 70x70, 80x80 cm. Obtained PDD values were compared with the calculated values using formula (1,2) (the conversion of PDD from FFD of 100 cm to 300 cm). The RFA3 water phantom used allows the maximum square field of 80x80 cm (FFD=300 cm), without the impact of the beam on the electronic part of the measuring system.

Program RTD II versions 3.0 (MULTIDATA) and the locally developed spreadsheet program called QW (version 7.0) have been used for parameter calculation.

The TMR factors were calculated through PDD using:

$$TMR[d,S] = \frac{1}{100} \times PDD[d, f, Sf/(f+d)]\frac{PSF[Sf/(f+d)]}{PSF[Sf/(f+d_m)]}\left(\frac{f+d}{f+d_m}\right)^2 \quad (3)$$

Obtained TMR data were compared by calculating their relative discrepancy (RD).

RESULTS AND DISCUSSION

Measurements in the horizontal beam at FFD=80 cm showed that there were no significant differences in the actual values of the beam parameters (PDD, TMR, OF) compared to those obtained when there was scattering from the floor (floor about 20 cm from the bottom of the phantom for vertical position of the beam), even when the depth was bigger. In this way the measuring system that "operates" at FF =300 cm was also tested.

The comparisons of the obtained PDD rectangular fields 40x60~(48 cm) at FFD=180 cm and 40x120~(60 cm) at FFD=300 cm with the obtained values for the square fields 50x50 and 60x60 cm respectively show good agreement (Table 1).

Table 1. Percent depth doses of square and rectangular fields at FFD=180 and 300 cm

depth (cm)	50x50 FFD= 180 cm	40x60 FFD= 180 cm	50x50 FFD= 300 cm	60x60 FFD= 180 cm	60x60 FFD= 300 cm	40x120 FFD= 300 cm	70x70 FFD= 180 cm	70x70 FFD= 300 cm	80x80 FFD= 300 cm
1.5	100	100	100	100	100	100	100	100	100
2	99.60	99.48	99.73	99.60	99.60	99.90	99.20	99.55	99.62
3	96.70	96.68	97.60	96.40	97.76	97.30	96.60	97.31	97.48
4	94.10	94.01	95.52	93.80	95.65	94.70	93.70	95.24	95.52
5	91.20	91.56	93.28	91.10	93.46	93.10	91.00	93.14	93.54
6	88.50	88.71	90.94	88.10	91.21	90.10	88.30	91.02	91.53
7	85.70	85.98	88.54	85.40	88.92	88.00	85.30	88.88	89.50
8	83.20	82.95	86.10	82.90	86.61	85.60	83.00	86.74	87.47
9	80.40	80.16	83.66	80.10	84.30	83.10	80.00	84.60	85.44
10	77.60	77.84	81.23	77.60	82.00	81.10	77.40	82.47	83.43
11	75.00	74.75	78.82	74.80	79.72	78.40	74.90	80.35	81.44
12	72.20	72.54	76.44	71.90	77.47	76.00	72.00	78.26	79.48
13	69.70	69.46	74.10	69.50	75.27	74.00	69.60	76.20	77.55
14	67.10	67.36	71.82	67.00	73.10	71.60	67.30	74.18	75.66
15	64.40	65.09	69.59	64.70	71.00	69.30	64.70	72.18	73.80
16	62.30	62.18	67.41	62.30	68.94	67.30	62.30	70.24	71.99
17	60.30	60.15	65.30	60.00	66.94	65.00	60.10	68.34	70.22
18	57.60	57.82	63.25	57.50	64.99	62.40	57.70	66.50	68.48
19	55.40	55.21	61.26	55.40	63.08	61.50	55.40	64.70	66.78
20	53.10	52.88	59.34	52.90	61.21	59.20	53.00	62.98	65.11
21	50.90	50.96	57.47	50.80	59.38	57.40	50.90	61.31	63.48
22	48.80	48.69	55.67	48.80	57.57	55.50	48.80	59.71	61.86

The differences in PDD values is the result of an incomplete equivalence of field dimensions (especially with regard to the field 40x120~(60 cm), which resulted in a reduced contribution of the scattered radiation from smaller sides in the measured point. The rectangular fields, whose one dimension (length) was 60 and 120 cm, were not measured against the full phantom (the reduced length of 5 and 35 cm appeared respectively for each side) However, it did not significantly affect the obtained results.

There is a good agreement between the calculated TMR values at FFD=300 cm (Table 2, column FFD=300 cm) and the calculated TMR values at FFD=180 cm (Table 2, column FFD=180 cm), but only for the fields of 30x30 and 40x40 cm. Agreement for the fields larger than 50x50 cm and at bigger depths was not so good (RD up to 10.5 percent), obviously because of deficiency of the phantom used. However, this situation is highly realistic in a clinical practice.

There is a good agreement between the measured OF values at FFD=300 cm (Table 3, column FFD=300 cm) with referential data at FFD=100 cm (Table 3, column FFD=100cm) and the measured values OF at FFD=180 cm (Table 3, column FFD=180 cm). The observed discrepancies OF (Table 3, column RD 100-300 and 180-300) are within the experimental error. OF for FFD=300 cm for all tested values are almost identical with referential ones at FFD=100 cm and the measured values at FFD=180 cm. The shortcomings of the phantom also had an impact on the rectangular fields, which is of greater relevance with bigger length of the fields. The machine output for square and rectangular fields measured by an absolute method showed good agreement. The discrepancy of output, originating from the inverse square law, was less than 2 percent and it is within the AAPM (7) recommendations. The scatter contribution from floor and walls of the treatment room was not observed under such measurement conditions. Four hundred MU was given for each field and it was measured at the depth of 5 cm, with referential dose rate of 320 (cGy/min) for the FFD=100 cm. In measurements taken at large FFD, a greater reliability was observed when the ionization chamber NE Farmer 2571A was used (absolute measurement) than while using the ionization chamber PTW 9732-2 (relative measurements) seemingly because of different characteristics of the two chambers.

Table 2. Comparison of the TMR for square fields at FFD=300 and 180 cm

		30x30			*40x40*			*50x50*			*60x60*			*70x70*		*80x80*
depth (cm)	FFD= 180cm	FFD= 300cm	R.D. (%)	FFD= 180cm	FFD= 300cm	R.D. (%)	FFD= 180cm	FFD= 300cm	R.D. (%)	FFD= 180cm	FFD= 300cm	R.D. (%)	FFD= 180cm	FFD= 300cm	R.D. (%)	FFD= 300 cm
1.5	1	1	0	1	1	0	1	1	0	1	1	0	1	1	0	1
2	0.998	0.998	0.03	0.996	0.999	0.26	0.995	0.998	0.26	0.998	0.999	0.09	0.997	0.997	0.04	0.997
3	0.987	0.986	-0.06	0.986	0.984	-0.20	0.984	0.988	0.37	0.98	0.988	0.80	0.982	0.981	-0.08	0.981
4	0.962	0.967	0.55	0.966	0.967	0.11	0.968	0.973	0.48	0.965	0.973	0.83	0.963	0.967	0.46	0.967
5	0.946	0.947	0.10	0.95	0.949	-0.13	0.948	0.956	0.86	0.946	0.957	1.14	0.946	0.952	0.67	0.952
6	0.929	0.926	-0.33	0.93	0.930	0.00	0.931	0.938	0.72	0.926	0.939	1.43	0.927	0.937	1.06	0.936
7	0.906	0.904	-0.26	0.913	0.910	-0.34	0.91	0.919	0.97	0.907	0.922	1.60	0.906	0.920	1.55	0.920
8	0.88	0.880	-0.01	0.89	0.889	-0.07	0.894	0.899	0.59	0.889	0.903	1.59	0.89	0.904	1.54	0.904
9	0.86	0.857	-0.36	0.87	0.868	-0.25	0.872	0.879	0.77	0.87	0.884	1.66	0.867	0.886	2.23	0.887
10	0.839	0.833	-0.67	0.847	0.846	-0.08	0.849	0.859	1.13	0.851	0.866	1.73	0.848	0.869	2.51	0.870
11	0.816	0.810	-0.78	0.828	0.825	-0.36	0.83	0.838	1.01	0.828	0.846	2.20	0.83	0.852	2.65	0.853
12	0.79	0.786	-0.46	0.804	0.804	-0.02	0.808	0.818	1.18	0.805	0.827	2.78	0.805	0.835	3.68	0.836
13	0.772	0.763	-1.15	0.784	0.782	-0.28	0.789	0.797	1.03	0.786	0.808	2.84	0.787	0.818	3.90	0.820
14	0.746	0.740	-0.76	0.76	0.760	0.00	0.767	0.777	1.24	0.764	0.789	3.32	0.769	0.800	3.98	0.803
15	0.725	0.718	-0.95	0.742	0.740	-0.22	0.744	0.757	1.77	0.747	0.771	3.16	0.747	0.782	4.73	0.786
16	0.704	0.697	-1.04	0.718	0.721	0.36	0.722	0.738	2.16	0.727	0.752	3.47	0.727	0.765	5.28	0.770
17	0.683	0.675	-1.11	0.698	0.700	0.32	0.703	0.718	2.18	0.707	0.735	3.90	0.708	0.749	5.72	0.754
18	0.663	0.654	-1.30	0.678	0.681	0.43	0.681	0.700	2.75	0.681	0.717	5.29	0.687	0.733	6.62	0.739
19	0.641	0.633	-1.23	0.655	0.661	0.98	0.662	0.681	2.93	0.666	0.699	4.97	0.666	0.716	7.54	0.723
20	0.619	0.613	-0.97	0.638	0.642	0.66	0.643	0.663	3.08	0.642	0.682	6.20	0.643	0.700	8.90	0.709
21	0.599	0.593	-0.95	0.616	0.624	1.25	0.622	0.646	3.78	0.623	0.665	6.79	0.624	0.684	9.68	0.694
22	0.58	0.573	-1.16	0.597	0.606	1.44	0.603	0.628	4.15	0.603	0.647	7.36	0.605	0.668	10.48	0.680

Table 3. OF of square and rectangular fields at FFD=100 cm, 180 cm and 300cm and relative discrepancies (RD %) for OF of square fields at FFD=300 cm, as opposed to FFD=100 cm and FFD=180 cm, as well as relative discrepancies OF of rectangular fields as compared with the square fields

quadr. (cm)	FFD= 100cm	FFD= 180cm	FFD= 300cm	R.D. 100-300 (%)	R.D. 180-300 (%)	rectang. 40x60 for180cm 40x120 for 300cm	R.D. qu.-rect. (%)
30	1.080	1.090	1.089	0.833	-0.092	-	-
35	1.092	1.100	1.101	0.824	0.091	-	-
40	1.101	1.108	1.109	0.727	0.090	-	-
45	-	1.114	1.117	-	0.269	-	-
50	-	1.125	1.125	-	0.000	1.126	0.089
55	-	1.128	1.131	-	0.266	-	-
60	-	1.136	1.137	-	0.088	1.147	0.880
65	-	1.142	1.142	-	0.000	-	-
70	-	1.147	1.146	-	-0.087	-	-
80	-	-	1.154	-	-	-	-

Table 4. Output for the square fields at FFD=300 cm

field size	30x30	30x30 expected output	40x40	40x40 expected output	50x50	60x60	40x120~[60]
Output (MU/cGy)	8.297	8.242 (R.D.= 0.663%)	8.157	8.092 (R.D.= 0.808%)	8.082	8	8.0170

CONCLUSION

We elaborated the application of methods of relative and absolute dosimetry by using the standard automatic water phantoms for the purpose of determining dosimetric characteristics of large radiation fields at increased distances form the focus of the device.

On the basis of the results obtained, a database of various parameters (PDD, TMR, OF, output, etc.) was set up to be used for the planning of radiation treatments with large fields (TBI, HBI, non-Hodgkin's lymphoma, Ewing's sarcoma, lymphosarcoma, neuroblastoma etc.) at increased FSD. The analysis of the obtained parameters as compared with referential dosimetry data (standard size of the field and standard distances) was carried out simultaneously.

For all examined sizes of square and rectangular fields, the measured values of outputs and output factors at FFD=180 and 300 cm comply, within the framework of experimental error, with referential values at 100 cm.

For fields up to dimensions of 40x40 cm at FFD=300 cm, a good agreement of all tested parameters (PDD and TMR) with those obtained at FFD=180 cm 100cm was observed. For larger fields the discrepancy in TMR is about maximum10 percent (square field of 70x70). Similar trend was observed with rectangular fields (one of the sides was at least twice longer than the other). These discrepancies were probably the result of an incomplete radiation scatter in the phantom whose dimensions were, after all, smaller. However, it was not possible to correct the mistake by using "unlimited" phantom instead of the "limited" one, due to technical reasons, but this situation is, in a clinical practice, more realistic than "unlimited phantom" situation.

Most of the dosimetric data obtained, point to the possibility of application of radiotherapy unit CLINAC 2100C (Varian) for therapies with large fields in given conditions (particular treatment room. However, additional dosimetry measurements need to be taken following the measurements on anthropomorphous phantom or relative dosimetry measurements using a phantom designed specifically for this purpose.

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