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Dosimetry measurements of radiation fields

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ABSTRACT

The Study was performed on a high-energy linear accelerator (Elekta Precise™). with built-in multileaf collimator (MLC) which produces two nominal photon energies (6MV and 15MV). Dosimetric measurements were carried out using linear accelerator (Elekta Precise™), PTW-UNIDOS Electrometer, a dual (0.125 cc) ion Chamber and Farmer (0.6 cc) ion Chamber, MEPHYSTO Version 7.3, and Therapy Beam Analyzer (MP3-S). Three-dimensional treatment planning (Precise PLAN) was used for calculating dose distribution. In this study, the physical properties characterizing high energy photon beams of (6MV and 15MV) that include the central axis percentage depth dose (CADD), beam profile specification, tissue maximum ratio (TMR), surface dose, buildup region and output factor, for different field sizes at different depths, were determined to show the effect of field size and beam energy on the central axis percentage depth dose also to show the effect of field size and depth on beam flatness, beam symmetry, penumbra, TMR and out put factor. Also in this study, the physical properties characterizing high energy photon beams of (6MV and 15MV) were measured and compared with the corresponding published data and calculated data by Precise PLAN (3DTPS).

KEYWORDS

LINAC;
Dosimetry;
Radiation oncology;
CAPDD;
Beam profile.

INTRODUCTION

Cancer is a disease in which abnormal cells in the body divide without control. Cancer affects people around the world, regardless of age, sex, and race or Socio-economic group. The World Health Organization (WHO) reported that cancer is the leading cause of death in the world, accounting for 7.9 million deaths in 2007, more than HIV/AIDS, malaria and tuberculosis combined[1].

According to WHO, many cancers can be prevented, others can be detected early, treated and cured, and palliative care can help patients with late stage cancer and help their families cope[2]. Oncology is an area of medicine that deals with the study and treatment of cancer. Treatment for cancer includes surgery, chemotherapy, radiation therapy, hormonal therapy and other targeted complementary and holistic approaches.

Photon radiation beams are normally used in radiation therapy for cancer disease. These radiation beams are almost produced from natural or artificial radiation sources. Such radiation sources must be under a quality control check to assure a precise and accurate dose delivery before and during the clinical applications. Program for periodic quality control checks is essential for radiation beam sources or machines that depend on the type of irradiation machine and at same time it must be including a radiation dosimetric, mechanical and electric measurements or checks. The radiation dosimetric part of quality control checks requires a precise determination of the physical characteristics for some different physical parameters are taken as reference guides for any periodic dosimetric quality control checks.

Modern medical linear accelerator (Linac) is sophisticated highly developed electronic machines generates a photon beam with different energies and in which it is impossible to guarantee that machine will run for ever without change performance or will never give any faults.

The precision and the accuracy of the linear accelerator are important at any time of radiation treatment, because it has direct effect on the quality of the patient treatment as it is known that the principle target of radiation therapy is to deliver accurate and uniform dose distribution to treated tumor volume at the same time to keep the dose to the normal tissue as low as possible. In which require a treatment machine to deliver a prescribed dose distribution to a prescribed target volume in reliable and safe manner.

The physical parameters that characterizing the photon beams of different energies is usually measured and analyzed to determine the different factors affecting it, and also to compare the measured data with calculated data and published data in order to maintain accurate dosimetry and uniform dose through the treatment volume, to have radiation treatment within standard quality, and at the same time is considered as a base line data which is essential part of Quality Assurance (QA) program in radiotherapy department.

Such QA program is necessary, in order to ensure consistency of beam dose characteristics, and optical integrity as well as maintaining a high degree of safety in the use of treatment equipment. As there is wide variety of occurrences that can unexpected changes in absorbed dose distribution.

EXPERIMENTAL DETAILS

This study was carried out using the measurement equipments and irradiation facilities, namely : (Elekta Precise™), PTW-UNIDOS Electrometer, a dual (0.125 cc) ion Chamber and Farmer (0.6 cc) ion Chamber, MEPHYSTO Version 7.3, and MP3-S water phantom connected to Therapy Beam Analyzer (MP3-S) and Three-dimensional treatment planning (Precise PLAN), used for all measurements required for verification, QA and analysis.

A central axis depth dose is measured for both 6 MV and 15 MV photon beams generated by Elekta Precise™ linac., using square field sizes ranged from 1x1 cm^2 to 40x40 cm^2 at FSD =100 cm. Dual ionization chambers (detector and reference) of volume 0.125 cc were connected with the dual channel PTW electrometer (TANDEM). The chambers are used with a three-dimensional MP3-S water phantom connected to MP3-S therapy beam analyzer system. The measurements are carried from zero to 35 cm depth in 1 mm increments then the collected data are stored and analyzed using the computer program MEPHYSTO version (7.3) and all depth dose data are normalized to the maximum depth dose (d_{max}) for both 6 MV and 15 MV x-ray beams.

Beam profiles are measured to characterize the dose at points off the central axis. Frequently off-axis data are normalized to the dose on the central axis at the same depth. These data are referred to as Off Axis Ratios (OARs), which are combined with central axis data to generate isodose curves.

Beam profiles measurements were experimentally determined using 0.125 cm^3 ionization chamber as in the case of depth dose measurements except in which the scanning ionization chamber moves transversely along x and y directions of the water phantom. The ionization chamber was scanned across the radiation field of square sides 5x5 cm^2 and 30x30 cm^2 with increment 2mm. The beam profiles were measured at depths in the range from d_{max} to 30 cm in a water phantom for each field size with a constant FSD of 100 cm.

Beam profile parameters are obtained by MEPHYSTO software that is used with automatic scanning system. These parameters are homogeneity (flatness), symmetry and penumbra. They are measured for both longitudinal and transverse axes of each field size at different depths. They are refer to the flattened region of the beam profile scan.

The homogeneity which is defined is by the equa-

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tion $\mathbf{homog.} = \frac{(\mathbf{D_{max}} - \mathbf{D_{min}})}{\mathbf{D_{max}} + \mathbf{D_{min}}} \mathbf{100\%}$, is calculated at field size measured with the 50% of the dose along the central axis, which is known as radiological field width[3]. D_{max} and D_{min} are the maximum and minimum dose within the flattened region referred to the dose value at the central axis respectively.

Symmetry is a measure of whether the beam's dose consistent on each side of the beam profile and is defined as the being maximum ratio within the flattened region, multiplied with 100[4,5].

$$\mathbf{Symmetry} = \left(\frac{\mathbf{D(x)}}{\mathbf{D(-x)}}\right)_{\mathbf{max}} \cdot \mathbf{100\%}$$

D(x) is the dose at point x; x and –x are points within the flattened region, symmetrical to the central axis.

Output Factors for different field sizes is measured relative to field size of a 10x10 cm^2 at the depth of 1.6 cm and 2.8 cm for 6 MV and 15 MV photon beams respectively to show the effect of field size on the value of output factor

Tissue Maximum Ratio (TMR) that defined as the ratio of the dose at a given point in phantom to the dose at the same point at the reference depth of the maximum dose, was determined as shown in the following steps

1- The condition for measurement of TMR was adjusted by the quality control for the machine according to the energy measured.
2- The absorbed dose was measured at the D_{max} according to the energy about 1.6 cm for 6 MV and 2.8 cm for 15 MV X-rays, for selected field size.
3- The thickness would be increased over the ionization chamber and the absorbed dose would be measured at the same field but at different depths D_d for the point of measurement.
4- Dividing D_d over the D_{max} yields the TMR.
5- The above step was repeated for deferent depths and for deferent field sizes.

Finally the complete dose distributions data measured for 6 MV and 15 MV photon beams of Elekta Precise™ linac were compared with the calculated data by Precise Plan and published data distributions. incident on water phantom.

RESULTS

The central axis percentage depth dose measurements

Figure 1 shows the central axis percent depth dose for both 6 MV and 15 MV x-ray beams respectively for different field sizes ranging from 1x1 cm^2 to 40x40 cm^2. They are characterized by the buildup of dose at the surface reaching a maximum dose at depth (d_{max}) then the dose decrease as the photon beam travels through the phantom beyond $d_{max.}$

TABLE 1 and corresponding Figure 2 show The measured percentage depth dose as a function in depth for photon beam energies 6 MV and 15 MV produced by Elekta Precise™ linac for open field sizes 5x5, 10x10, 15x15, 20x20, and 30x30 cm^2 at SSD=100 cm. This data illustrates the influence of beam energy on the percentage depth dose curves for different field sizes

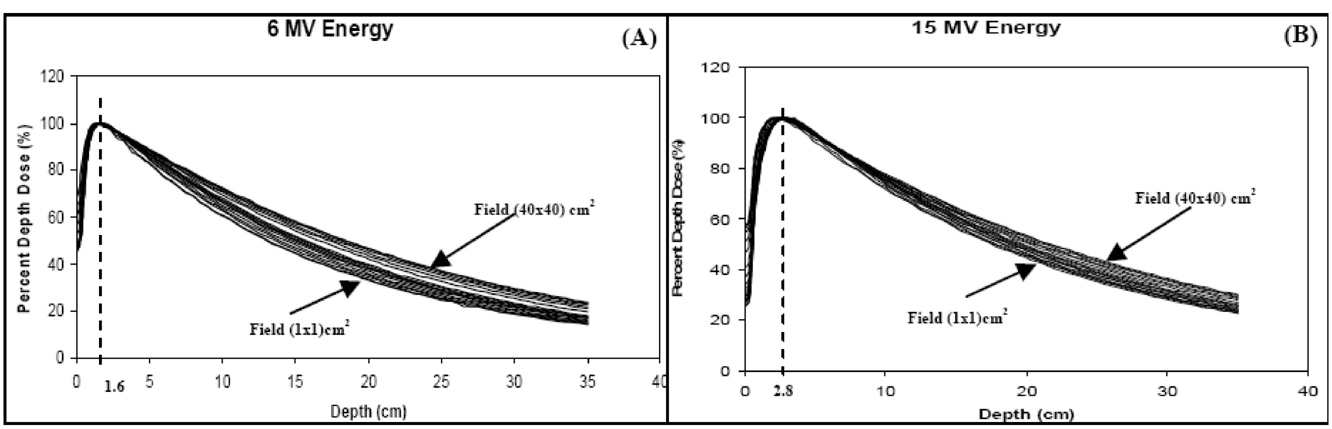

Figure 1 : The central axis PDD of photon beams generated by Elekta Precise™ linac. measured for open square fields sizes ranged from (1x1)cm² to (40x40) cm² at FSD = 100 cm in water phantom, normalized to d_{max} for beam energies (A) 6 MV and (B)15 MV

TABLE 1 : The measured central axis PDD for 6 MV and 15 MV photon beam of Elekta Precise™ linac

Field size(cm)		5x5 cm^2		10x10 cm^2		15x15 cm^2		20x20 cm^2		30x30 cm^2	
Depth(cm)	Energy	6MV	15MV	6MV	15MV	6MV	15MV	6MV	15MV	6MV	15MV
0		46.1	26.8	51.0	34.1	54.9	40.8	59.0	46.7	64.0	54.5
0.2		49.6	28.4	55.1	35.6	59.3	42.0	63.9	48.2	66.8	56.0
0.4		64.1	34.2	68.8	39.5	74.0	47.6	76.5	54.4	76.5	61.6
0.6		79.9	58.7	83.9	61.7	86.1	67.2	88.6	73.6	91.2	79.8
0.8		88.5	68.2	90.4	74.9	92.4	79.0	93.6	83.2	95.6	86.9
1.0		94.3	77.2	95.7	82.4	96.8	85.7	97.8	88.8	98.5	91.5
1.2		97.7	83.5	98.6	87.7	99.2	90.6	99.4	93.1	99.6	95.1
1.4		99.2	87.3	99.5	91.5	99.6	93.8	100.0	95.8	100.0	96.8
1.6		100.0	91.6	100.0	94.7	100.0	96.0	99.8	97.7	99.7	98.2
1.8		99.5	94.2	99.9	96.1	99.9	98.3	99.8	98.3	99.7	99.6
2.0		99.2	96.2	99.3	98.1	99.4	98.9	98.8	99.4	99.0	99.8
2.8		95.6	100.0	95.9	100.0	96.0	99.8	95.9	99.3	95.8	99.4
6.0		80.9	89.6	82.8	90.0	83.9	89.6	84.2	89.2	84.8	89.6
7.0		76.9	85.6	79.1	86.1	80.5	86.3	80.1	85.6	81.5	86.4
8.0		72.4	82.0	75.6	82.8	76.7	82.7	77.5	82.7	78.3	83.1
9.0		68.2	77.5	71.2	79.1	72.9	79.3	73.5	80.1	74.8	79.9
10.0		64.2	74.0	67.9	76.2	69.6	76.5	70.6	76.6	71.8	77.1
11.0		61.0	70.7	64.4	72.5	66.1	73.5	67.3	73.5	68.6	74.3
12.0		57.3	67.0	61.0	69.5	63.0	70.1	64.2	70.8	65.6	71.8
13.0		53.9	64.6	57.8	66.3	60.1	67.6	61.3	67.7	62.9	68.8
14.0		51.1	61.6	54.8	63.7	57.1	64.8	58.5	65.3	59.9	66.1
15.0		48.2	58.4	51.8	61.2	54.2	62.2	55.6	62.7	57.3	63.4
16.0		45.3	55.8	49.2	58.2	51.5	59.5	52.9	59.9	54.9	61.2
17.0		42.9	53.5	46.6	56.1	49.0	57.1	50.5	58.0	52.5	59.0
18.0		40.3	51.1	44.2	53.5	46.5	54.9	48.2	55.6	50.2	56.7
19.0		38.0	48.8	41.8	51.1	44.3	52.6	45.6	53.1	47.7	54.4
20.0		36.0	46.6	39.7	48.9	42.0	50.5	43.6	51.1	45.7	52.6
21.0		34.0	44.0	37.7	46.7	39.9	48.2	41.5	49.4	43.8	50.3
22.0		32.1	42.5	35.4	44.9	37.9	46.2	39.4	47.3	41.5	48.5
23.0		30.5	40.3	33.8	43.0	36.2	44.4	37.4	45.5	39.9	46.6
24.0		28.6	38.8	32.0	41.4	34.4	42.7	35.8	43.7	37.9	44.8
25.0		27.2	36.7	30.3	39.5	32.5	40.9	33.9	42.0	36.2	43.2
26.0		25.7	35.3	28.9	37.6	31.0	39.2	32.5	40.1	34.4	41.5
27.0		24.3	33.5	27.3	36.3	29.4	37.6	30.9	38.6	32.8	40.0
28.0		23.0	32.0	25.8	34.4	28.0	35.9	29.3	36.8	31.3	38.6
29.0		21.7	30.5	24.6	33.1	26.7	34.7	28.1	35.4	30.0	37.0
30.0		20.6	29.5	23.3	31.7	25.5	33.3	26.8	34.0	28.5	35.5
31.0		19.4	27.9	22.0	30.3	24.0	31.7	25.3	32.7	27.3	34.1
32.0		18.4	27.0	21.0	29.0	23.0	30.6	24.2	31.6	26.1	32.8
33.0		17.4	25.7	20.0	28.0	21.7	29.3	23.1	30.3	24.8	31.7
34.0		16.5	24.5	18.8	26.8	20.6	28.2	21.9	28.9	23.8	30.4
35.0		15.7	23.5	18.0	25.7	19.6	27.0	21.0	27.9	22.7	29.2

Beam profile measurements for elekta precise™ linac

The resulting beam profile scans demonstrate the variation in flatness, symmetry and penumbra, for different field sizes as a function of the specified depths for both 6MV and 15 MV energies.

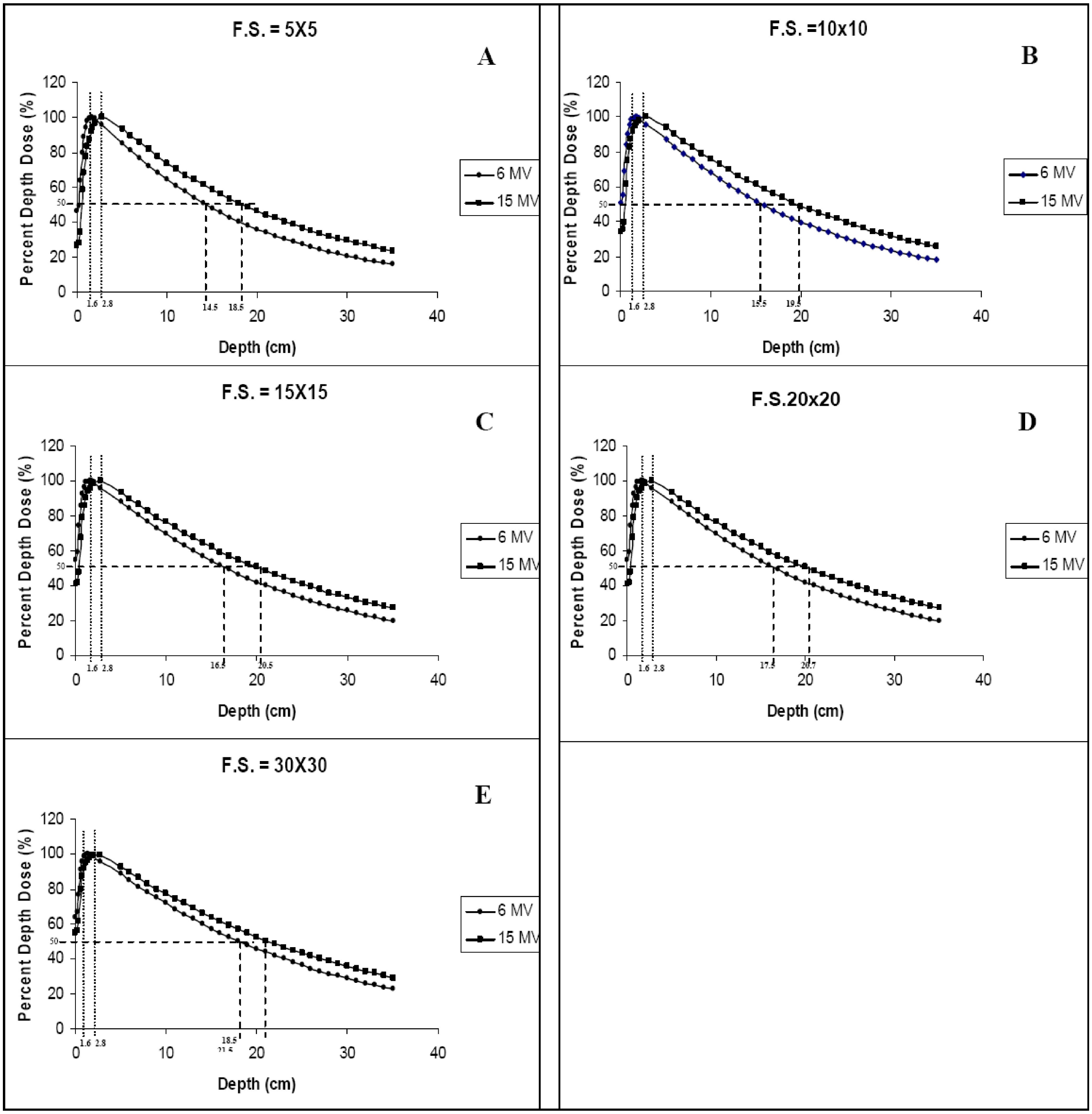

Figure 2 : The central axis PDD curves for 6 MV and 15 MV photon beams of Elekta Precise™ linac. normalized to 100% at d_{max} for field size: (A) 5x5 cm^2, (B) 10x10 cm^2,(C)15x15 cm^2,(D)20x20 cm^2 and (E) 30x30 cm^2.

Figure 3 shows an open beam profile measurements of 6 MV photon beam generated by Elekta Precise™ Linac, for field sizes 5x5 cm^2, 10x10 cm^2, 15x15 cm^2, 20x20 cm^2 and 30x30 cm^2 at depths ranging from d_{max} to 30 cm. Dual ionization chambers (detector and reference) of volume 0.125 cc were connected with the dual channel PTW electrometer (TANDEM). The chambers was used with a three-dimensional MP3-S water phantom connected to MP3-S therapy beam analyzer system. The radiation beam was measured at FSD =100 cm.

Figure 4 shows an open beam profile measurements of 15 MV Elekta Precise™ Linac. are carried out under the same conditions.

TABLE 2 shows the homogeneity (flatness), symmetry and penumbra (left and right) at specified depths for field sizes 5x5, 10 x 10, 15x15, 20 x 20, and 30x30 cm^2 respectively for 6 MV photon beam, while TABLE 3 shows the homogeneity (flatness), symmetry and penumbra (left and right) at specified depths for field sizes

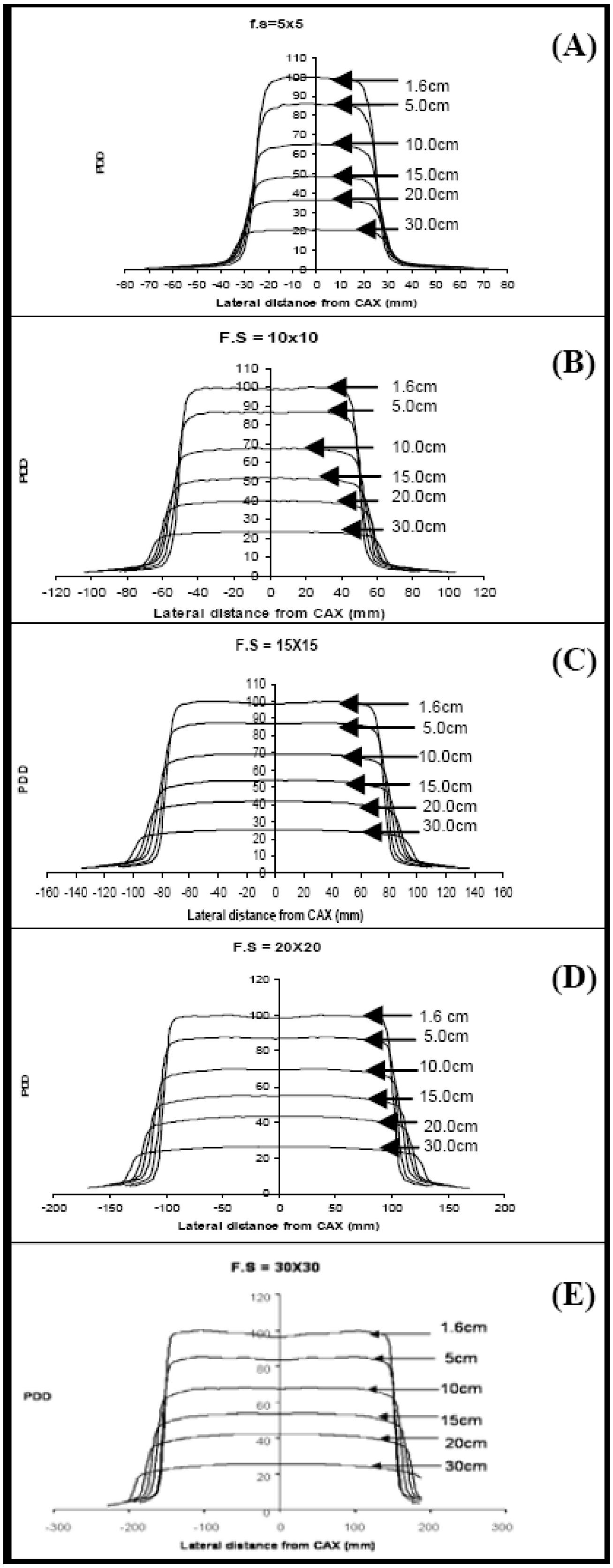

Figure 3 : 6 MV beam profile of Elekta Precise™ linac. scans at depths of (1.6, 5, 10, 15, 20, and 30 cm) for field size: (A) 5x5 cm², (B) 10x10 cm², (C) 15x15 cm², (D) 20x20 cm² and (E) 30x30 cm²

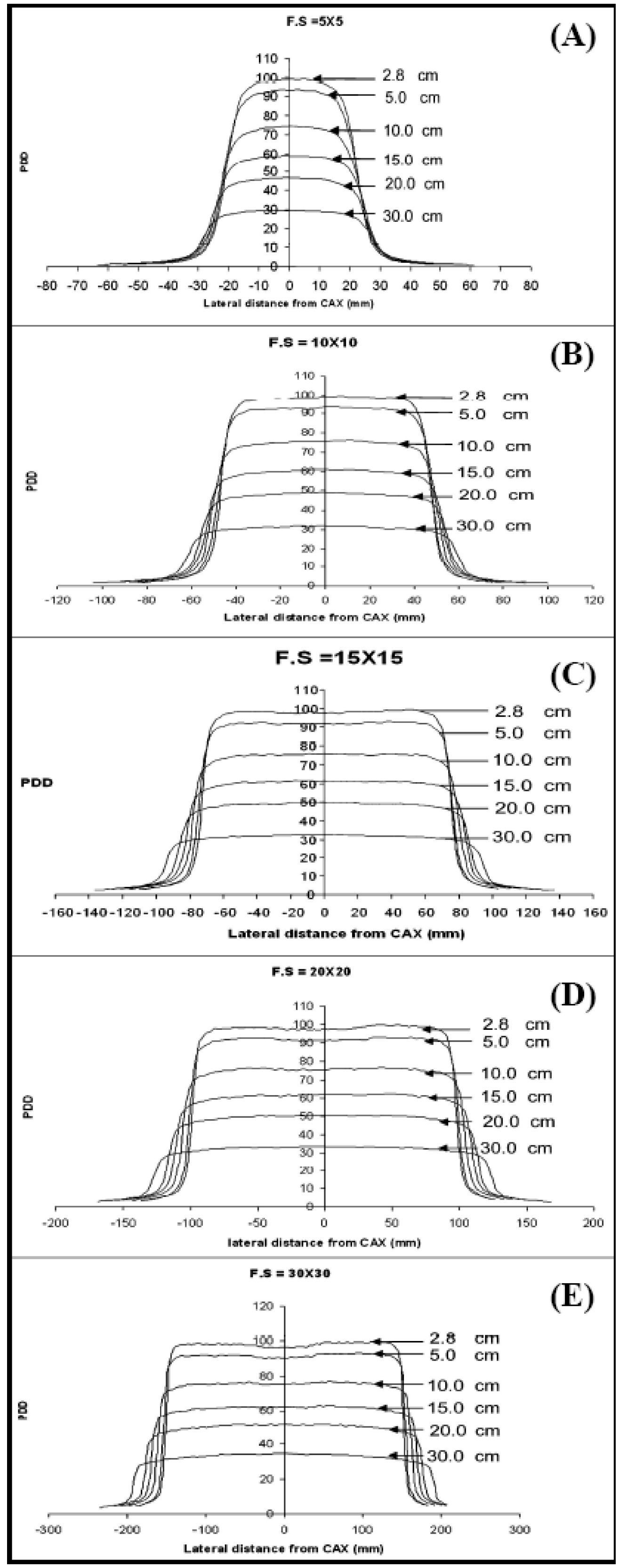

Figure 4 : 15 MV beam profile of Elekta Precise™ linac. scans at depths of (1.6, 5, 10, 15, 20, and 30 cm) for field size: (A) 5x5 cm², (B) 10x10 cm², (C) 15x15 cm², (D) 20x20 cm² and (E) 30x30 cm²

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TABLE 2: The homogeneity (flatness), symmetry, and penumbra left and right for field sizes 5x5 cm² 10x10 cm², 15x15 cm², 20x20 cm² and 30x30 cm²

Depth (cm)	Penumbra Left (mm)	Penumbra Right (mm)	Flatness (%)	Symmetry (%)
Field Size 5x 5 (cm²)				
1.6	5.61	5.38	0.66	100.89
5.0	5.80	5.97	1.16	100.58
10.0	6.44	6.18	1.54	100.63
15.0	6.73	6.65	1.60	100.58
20.0	7.00	6.77	1.58	100.69
30.0	7.55	7.30	2.11	101.06
Field Size 10 x 10 (cm²)				
1.6	5.81	5.60	0.88	100.97
5.0	6.41	6.36	1.46	100.43
10.0	7.23	6.97	2.27	100.51
15.0	8.10	7.94	2.99	101.04
20.0	8.66	8.60	3.43	100.84
30.0	10.37	10.22	3.64	100.93
Field Size 15 x 15 (cm²)				
1.6	7.20	7.08	0.90	100.69
5.0	7.80	7.97	1.22	100.66
10.0	9.23	9.09	2.31	100.89
15.0	10.53	10.45	3.22	100.78
20.0	11.78	11.65	3.99	100.37
30.0	15.20	15.18	4.97	100.49
Field Size 20 x 20 (cm²)				
1.6	7.80	7.56	0.91	100.50
5.0	8.66	8.55	0.99	100.42
10.0	10.30	10.17	2.22	100.65
15.0	12.07	11.82	3.36	100.43
20.0	13.86	13.90	4.08	100.58
30.0	19.64	19.75	5.65	100.50
Field Size 30 x 30 (cm²)				
1.6	8.25	8.32	1.01	100.66
5.0	9.50	9.39	1.14	100.43
10.0	11.76	11.50	2.13	100.36
15.0	14.17	14.08	3.83	100.8
20.0	18.08	-	5.31	100.33
30.0	-	-	-	-

5x5, 10 x 10, 15x15, 20 x 20, and 30x30 cm² respectively for 15 MV photon beam.

Figure 5 shows the linearity between penumbra width and depth for field sizes (5x5, 10x10, 15x15 and 20x20 cm²). of 6 MV photon beam. While Figure 6 show the linearity between penumbra width and depth for field sizes (5x5, 10x10, 15x15, 20x20 and 30x30 cm²). of 15 MV photon beam.

TABLE 3 : The homogeneity (flatness), symmetry, and penumbra left and right for field sizes 5x5 cm² 10x10 cm², 15x15 cm², 20x20 cm² and 30x30 cm² as a function of depth (cm) for 15MV photon beam emerged from Elekta Precise™ linac.

Depth (cm)	Penumbra Left (mm)	Penumbra Right (mm)	Flatness (%)	Symmetry (%)
Field Size 5x 5 (cm²)				
2.8	7.11	6.28	1.78	100.51
5.0	7.18	7.23	1.81	101.86
10.0	7.45	7.79	2.45	101.99
15.0	7.90	7.84	2.27	102.25
20.0	8.22	8.01	2.89	102.39
30.0	8.51	8.36	3.00	101.83
Field Size 10 x 10 (cm²)				
2.8	7.38	6.90	2.07	102.40
5.0	7.73	7.32	2.19	101.55
10.0	8.23	7.8	2.96	101.90
15.0	9.09	8.56	3.38	102.25
20.0	9.91	9.28	3.77	101.84
30.0	10.8	10.46	3.94	102.23
Field Size 15 x 15 (cm²)				
2.8	7.56	7.12	1.39	101.99
5.0	7.92	7.48	1.58	101.82
10.0	8.70	8.11	2.25	102.00
15.0	9.97	9.46	2.69	102.35
20.0	10.77	10.51	3.29	102.29
30.0	12.84	12.54	4.19	101.92
Field Size 20 x 20 (cm²)				
2.8	7.59	7.29	1.45	101.94
5.0	8.12	7.66	1.50	101.66
10.0	9.26	8.68	2.01	101.45
15.0	10.27	10.33	3.01	102.28
20.0	11.50	11.38	3.51	102.03
30.0	14.66	14.12	4.70	101.61
Field Size 30 x 30 (cm²)				
2.8	7.70	7.22	1.84	101.81
5.0	7.91	7.64	1.94	101.68
10.0	9.65	9.09	2.20	102.00
15.0	11.31	10.88	3.34	102.24
20.0	12.75	12.86	4.51	102.16
30.0	17.49	17.18	6.61	101.88

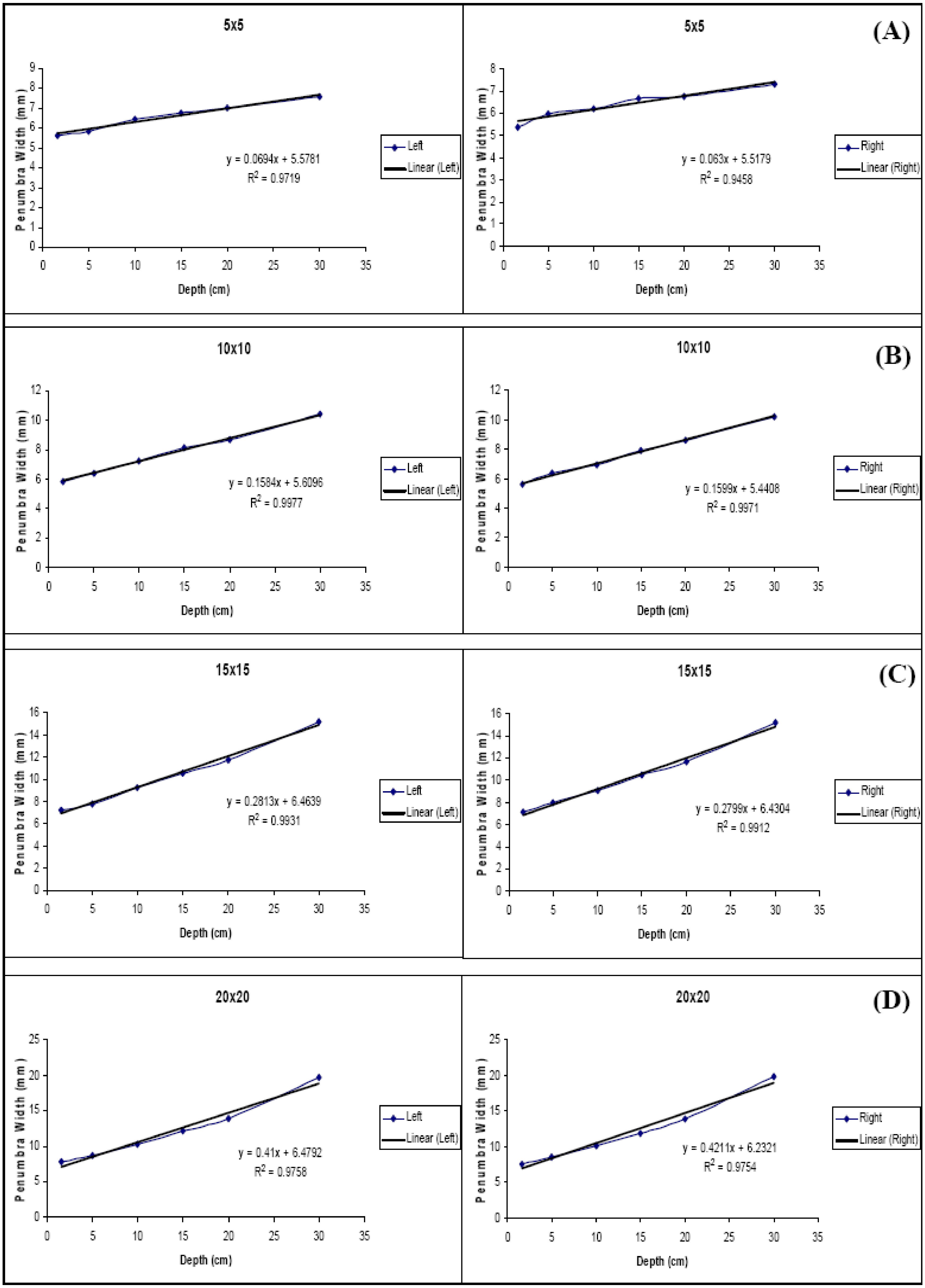

Figure 5 : The linearity between penumbra width and depth for 6MV photon beam emerged from Elekta Precise™ linac. with field size : (A) 5x5 cm², (B) 10x10 cm², (C) 15x15 cm², (D) 20x20 cm²

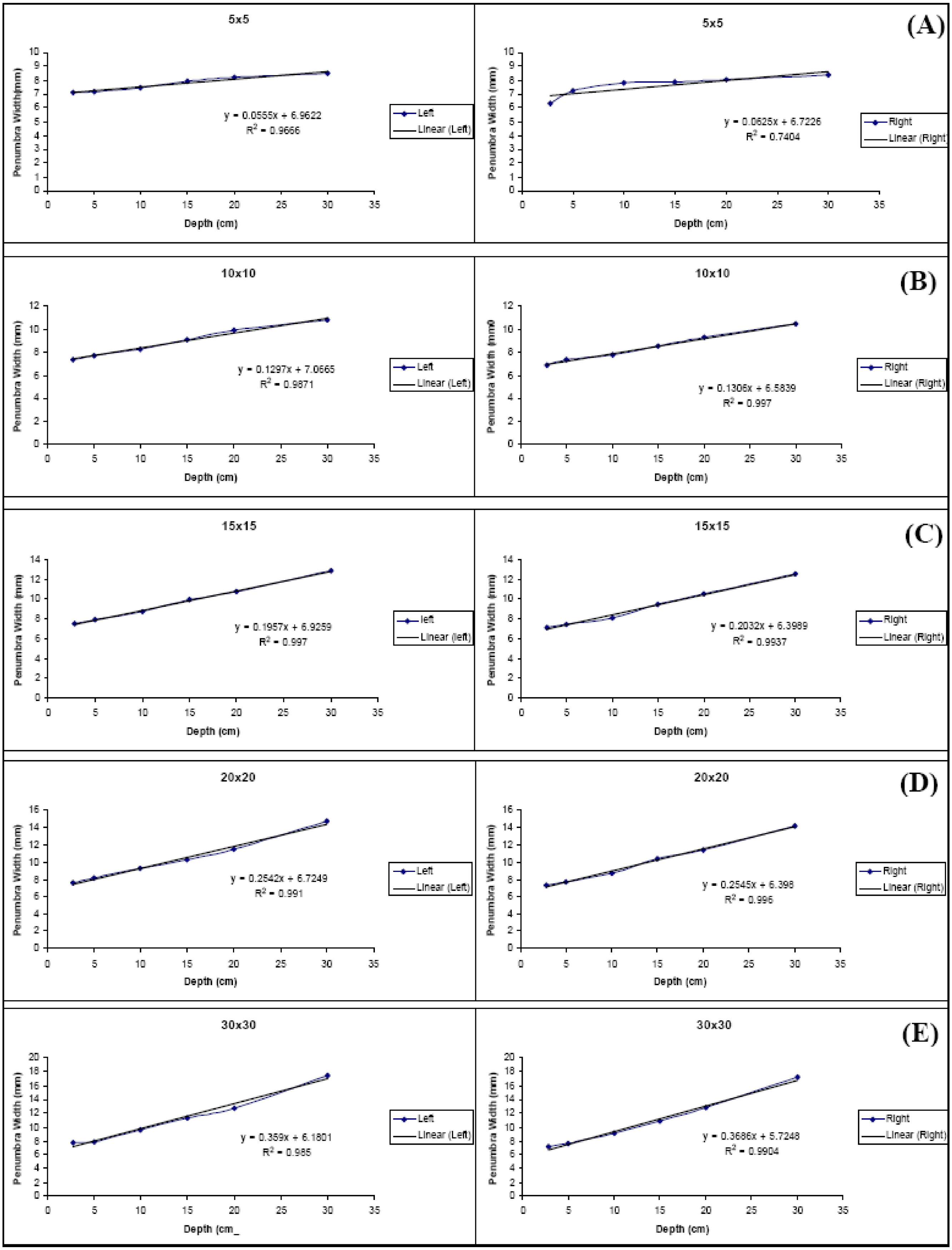

Figure 6 : The linearity between penumbra width and depth for 15 MV photon beam emerged from Elekta Precise™ linac. with field size : (A) 5x5 cm^2, (B) 10x10 cm^2, (C) 15x15 cm^2, (D) 20x20 cm^2 and (E) 30x30 cm^2.

Tissue maximum ratio (TMR) were determined for 6 MV and 15 MV photon beam immerged form Elekta Precise™ linac. at FSD =100 cm for field sizes from 5x5 cm^2 to 30x30 cm^2, the reference depth for normalization of TMR is 1.6 cm for 6 MV photon beam and 2.8 for 15 MV photon.

TABLE 4 and 5 represent TMR related to depth for field sizes from 5x5 cm^2 to 30x30 cm^2 compared with the published data[6] for 6 MV 15 MV photon beam emerged from Elekta Precise™ linac, and the measured data were plotted in Figure 7.

TABLEs 6 and 7 and Figure 8 show the measured output factors for different field sizes relative to field size of a 10x10 cm^2 at the depth of 1.6 cm and 2.8 cm

TABLE 4 : The measured (M) TMR for 6MV photon beam emerged from Elekta Precise™ linac. compared with the published (P)[6] TMR for square field sizes(5x5) , (10x10) , (15x15), (20x20) and (30x30) cm^2.

Field size (cm^2)	5 x 5		10 x 10		15 x15		20 x 20		30 x 30	
Depth(cm)	P	M	P	M	P	M	P	M	P	M
1.0	-	0.966	-	0.968	-	0.969	-	0.971	-	0.975
1.6	-	1.000	-	1.000	-	1.000	-	1.000	-	1.000
2.0	0.996	0.994	0.998	0.994	0.997	0.994	0.996	0.995	0.997	0.996
3.0	0.973	0.971	0.979	0.977	0.980	0.977	0.981	0.979	0.982	0.981
4.0	0.943	0.939	0.954	0.951	0.958	0.956	0.960	0.959	0.964	0.963
5.0	0.910	0.907	0.928	0.925	0.935	0.931	0.939	0.937	0.945	0.942
6.0	0.878	0.874	0.900	0.887	0.910	0.906	0.916	0.913	0.925	0.921
7.0	0.843	0.841	0.871	0.868	0.884	0.882	0.893	0.891	0.904	0.902
8.0	0.810	0.808	0.843	0.841	0.860	0.859	0.869	0.868	0.882	0.879
9.0	0.777	0.773	0.814	0.811	0.833	0.831	0.844	0.842	0.860	0.858
10.0	0.745	0.741	0.786	0.784	0.808	0.805	0.820	0.817	0.837	0.835
15.0	0.603	0.601	0.650	0.648	0.681	0.679	0.701	0.698	0.726	0.723
20.0	0.484	0.482	0.532	0.531	0.565	0.562	0.587	0.585	0.620	0.619
25.0	0.389	0.386	0.433	0.429	0.466	0.464	0.490	0.488	0.525	0.522
30.0	0.313	0.311	0.352	0.351	0.382	0.381	0.406	0.403	0.441	0.439

TABLE 5 : The measured (M) TMR for 15MV photon beam emerged from Elekta Precise™ linac. compared with the published (P)[6] TMR for square field sizes(5x5) , (10x10) , (15x15), (20x20) and (30x30) cm^2.

Field size (cm^2)	5 x 5		10 x 10		15 x15		20 x 20		30 x 30	
Depth (cm)	P	M	P	M	P	M	P	M	P	M
1.0	-	0.977	-	0.981	-	0.985	-	0.987	-	0.985
2.0	-	0.986	-	0.983	-	0.988	-	0.986	-	0.989
2.8	-	1.000	-	1.000	-	1.000	-	1.000	-	1.000
3.0	1.000	0.999	1.000	0.998	1.000	0.996	0.999	0.995	0.999	0.994
4.0	0.999	0.998	0.997	0.995	0.992	0.991	0.990	0.990	0.988	0.987
5.0	0.984	0.982	0.984	0.983	0.979	0.975	0.975	0.974	0.973	0.971
6.0	0.962	0.959	0.964	0.962	0.961	0.958	0.959	0.957	0.957	0.955
7.0	0.938	0.937	0.944	0.941	0.942	0.941	0.940	0.938	0.939	0.936
8.0	0.912	0.909	0.922	0.919	0.922	0.921	0.921	0.918	0.922	0.921
9.0	0.887	0.885	0.899	0.896	0.900	0.898	0.901	0.899	0.904	0.902
10.0	0.862	0.861	0.877	0.875	0.881	0.879	0.883	0.881	0.888	0.886
15.0	0.743	0.739	0.768	0.767	0.780	0.778	0.786	0.783	0.799	0.797
20.0	0.641	0.639	0.669	0.667	0.686	0.684	0.696	0.694	0.713	0.711
25.0	0.553	0.551	0.581	0.579	0.600	0.599	0.613	0.612	0.632	0.629
30.0	0.474	0.472	0.504	0.502	0.524	0.522	0.538	0.536	0.559	0.556

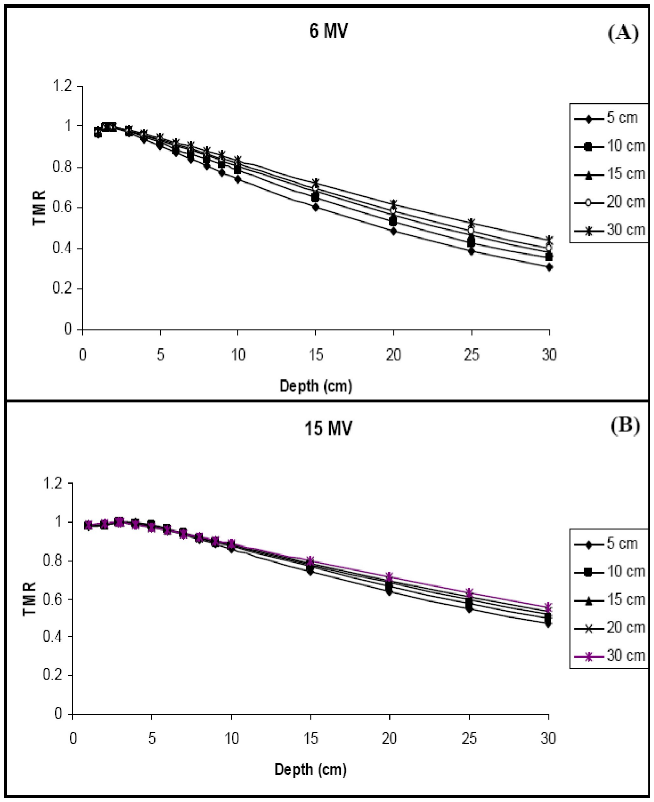

Figure 7 : The TMR of photon beam emerged from Elekta Precise™ linac for square fields of sides 5, 10, 15, 20 and 30 cm at FSD = 100 cm, for beam energies (A) 6MV and (B) 15 MV.

for 6 MV and 15 MV photon beams respectively.

Dosimetric verification for photon beam

The central axis depth dose was measured for both 6 MV and 15 MV photon beam generated by Elekta Precise™ linac for square field sizes ranged from (5x5) cm^2 to (30x30) cm^2 at SSD =100 cm. The measurements are carried from zero to 30 cm in depth of 5 mm increments. The collected data is stored and analyzed using the computer program MEPHYSTO version 7.3. The depth dose data is normalized to the maximum depth dose (d_{max}) at 1.6 cm for 6MV and 2.8 for 15 MV on the central axis. The measured percentage depth dose data of 6 MV and 15 MV photon beam produced by the Elekta Precise™ linac. was compared with calculated data by using Precise PLAN and that corresponding published data[6,8]

TABLE 8 and Figure 9 show the measured central axis PDD compared with the calculated data, and the published data[8] for 6 MV photon beam for (5x5),(10x10), (15x15), (20x20) and (30x30) cm^2 field sizes., while TABLE 9 and Figure 10 show the measured central axis PDD compared with the calculated data, and the published data[6] for 15 MV photon beam for (5x5), (10x10), (15x15), (20x20) and (30x30) cm^2 field sizes.

Beam profiles were measured in water using ion chamber and PTW system for open field sizes (5x5,

TABLE 6 : The output factors for different field sizes at depth d_{max} cm for 6 MV photon emerged from Elekta Precise™ linac.

Field size (cm^2)	Output factor
4x4	0.92
5x5	0.94
6x6	0.95
7x7	0.97
8x8	0.98
9x9	0.99
10x10	1.00
11x11	1.01
12x12	1.02
12.5X12.5	1.02
15X15	1.03
17.517.5	1.05
20X20	1.05
25X25	1.05
30X30	1.07
35X35	1.08
40X40	1.08

TABLE 7 : The output factors for different field sizes at depth d_{max} cm for 15 MV photon emerged from Elekta Precise™ linac.

Field size (cm^2)	Output factor
4x4	0.93
5x5	0.95
6x6	0.96
7x7	0.97
8x8	0.98
9x9	0.99
10x10	1.00
11x11	1.00
12x12	1.01
15x15	1.02
17.5x17.5	1.03
20x20	1.05
25x25	1.05
30x30	1.07
35x35	1.08
40x40	1.09

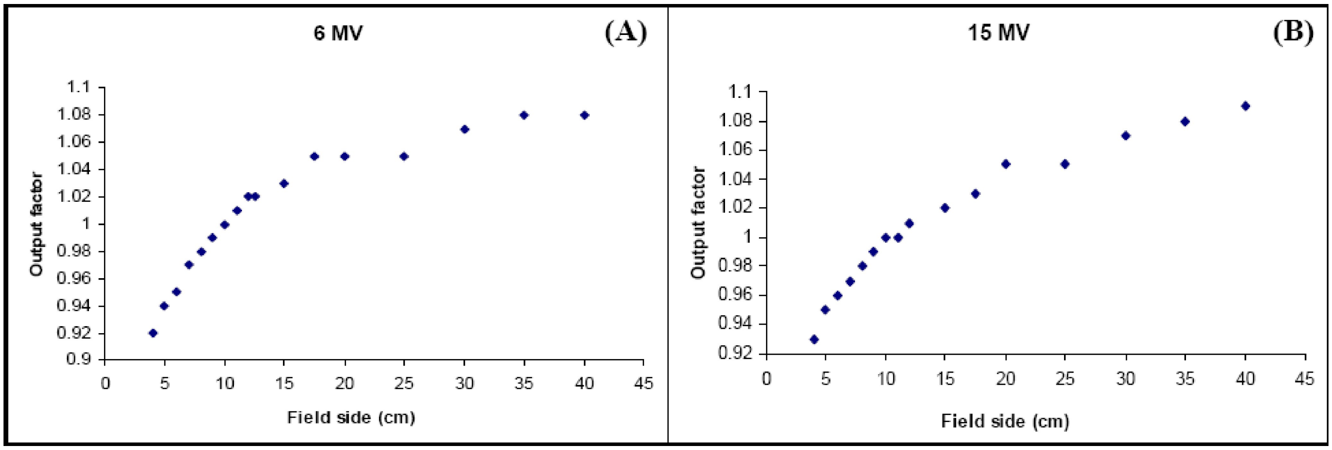

Figure 8 : The output factors for different field sizes relative to field size of a (10x10) cm^2 at depth d_{max} cm for photon beam emerged from Elekta Precise™ linac with energy (A) 6MV and (B) 15 MV

TABLE 8 : Measured PDD for 6MV photon beam emerged from Elekta Precise™ linac. compared with calculated and published[7] PDD.

Field Size	5X5 cm^2			10X10 cm^2			15X15 cm^2			20X20 cm^2			30X30 cm^2		
D(cm)	PTW	TPS	P	PTW	TPS	P	PTW	TPS	P	PTW	TPS	P	PTW	TPS	P
1.0	94.3	95.3	98.5	95.74	98.1	99.0	96.8	96.0	99.4	97.8	98.5	99.5	98.5	99.0	99.5
1.6	100.0	100.0	-	100.0	100.0	-	100.0	100.0	-	99.8	100.0	-	99.9	100.0	-
2.0	99.2	99.0	98.6	99.3	99.0	98.8	99.4	99.0	98.7	98.8	98.5	98.6	99.0	99.0	98.7
3.0	94.0	94.0	94.5	95.9	95.6	95.1	96.0	96.0	95.2	95.9	95.8	95.3	95.8	95.5	95.4
4.0	89.8	89.8	89.9	91.1	91.0	91.0	91.3	91.3	91.4	91.7	91.5	91.5	91.7	91.5	91.9
5.0	85.4	85.3	85.2	87.2	87.0	86.9	88.0	87.9	87.5	88.2	88.0	87.9	88.6	88.5	88.5
6.0	80.9	80.6	80.6	82.8	82.5	82.8	83.9	83.6	83.7	84.2	84.0	84.2	84.8	84.5	85.0
7.0	76.9	76.4	76.2	79.1	79.0	78.8	80.5	80.0	79.9	80.8	80.9	80.7	81.5	81.4	81.6
8.0	72.4	72.3	71.9	75.6	75.4	74.9	76.7	76.6	76.3	77.5	77.2	77.1	78.3	78.3	78.2
9.0	68.2	68.0	67.8	71.2	71.0	71.1	72.9	72.5	72.7	73.5	73.3	73.7	74.8	74.5	75
10.0	64.2	64.1	64.0	67.9	67.6	67.5	69.6	69.0	69.3	70.6	70.4	70.4	71.8	71.5	71.7
11.0	61.0	59.9	60.3	64.4	64.0	64.0	66.1	65.5	66.0	67.3	67.0	67.2	68.6	68.0	68.6
12.0	57.3	57.3	56.9	61.0	61.0	60.7	63.0	62.5	62.8	64.2	64.0	64.1	65.6	65.3	65.7
13.0	53.9	53.8	53.7	57.8	57.5	57.6	60.1	59.5	59.8	61.3	61.0	61.2	62.9	62.5	62.8
14.0	51.1	51.0	50.6	54.8	54.6	54.5	57.1	57.0	56.8	58.5	58.0	58.2	59.9	59.5	59.9
15.0	48.2	48.0	47.7	51.8	51.7	51.7	54.2	54.0	54.0	55.6	55.0	55.5	57.3	56.9	57.3
16.0	45.3	45.0	44.9	49.2	49.0	48.9	51.5	51.0	51.3	52.9	53.0	52.8	54.9	54.5	54.7
17.0	42.9	42.9	42.3	46.6	46.5	46.3	49.0	49.0	48.7	50.5	50.0	50.3	52.5	52.0	52.3
18.0	40.3	40.0	39.9	44.2	44.1	43.8	46.5	46.0	46.2	48.2	47.9	47.9	50.2	50.0	49.9
19.0	38.0	38.0	37.6	41.8	41.5	41.5	44.3	44.0	43.9	45.6	45.2	45.6	47.7	47.3	47.6
20.0	36.0	36.0	35.5	39.7	39.5	39.3	42.0	42.0	41.7	43.6	43.3	43.4	45.7	45.2	45.4
22.0	32.1	32.1	33.5	35.4	35.4	35.2	37.9	37.5	37.6	39.4	39.0	39.3	41.5	41.3	41.3
24.0	28.6	28.5	28.2	32.0	32.0	31.6	34.4	34.0	33.9	35.8	35.5	35.5	37.9	37.5	37.6
26.0	25.7	25.6	25.1	28.9	28.9	28.3	31.0	30.8	30.6	32.5	32.0	32.1	34.4	34.0	34.1
28.0	23.0	22.8	22.4	25.8	25.8	25.4	28.0	28.0	27.6	29.3	29.0	29.1	31.3	31.0	31.0
30.0	20.6	20.6	20.0	23.3	23.0	22.8	25.5	25.0	24.8	26.8	26.0	26.3	28.5	28.0	28.2

10x10, 15x15, 20x20 and 30x30 cm^2) at 100 cm SSD for the 6 MV and 15 MV photon beam generated by Elekta Precise™ linac. and compared with the calculated beam profiles by Three-dimensional treatment planning (Precise PLAN).

Figure 11 shows the measured beam profiles for

TABLE 9 : Measured PDD for 15MV photon beam emerged from Elekta Precise™ linac. compared with calculated and published[6] PDD.

Field Size	5X5 cm^2			10X10 cm^2			15X15 cm^2			20X20 cm^2			30X30 cm^2		
D(cm)	PTW	TPS	P	PTW	TPS	P	PTW	TPS	P	PTW	TPS	P	PTW	TPS	P
1.0	77.2	77.0	-	82.44	82.0	-	85.7	85.5	-	88.8	88.8	-	91.5	91.4	-
2.0	96.2	96.0	-	98.12	98.0	-	98.9	98.8	-	99.4	99.4	-	99.8	99.8	-
2.8	100.0	100.0	-	100.0	100.0	-	99.8	99.9	-	99.3	99.8	-	99.4	99.6	-
3.0	99.4	99.0	99.8	99.9	99.8	99.8	99.4	99.3	99.8	98.6	98.5	99.7	98.9	98.8	99.7
4.0	97.2	97.0	97.8	96.9	96.7	97.6	96.1	96.0	97.1	96.3	96.0	96.9	95.9	95.8	96.7
5.0	93.5	93.3	94.6	93.8	93.4	94.5	93.4	93.3	94.0	92.5	92.4	93.7	92.9	92.9	93.5
6.0	89.6	89.5	90.8	90.0	90.0	90.9	89.6	89.5	90.6	89.2	89.0	90.4	89.6	89.6	90.3
7.0	85.6	85.4	86.9	86.1	86.0	87.4	86.3	86.3	87.2	85.6	85.3	87	86.4	86.3	87.0
8.0	82.0	82.0	83.0	82.8	82.6	83.8	82.7	82.5	83.8	82.7	82.5	83.7	83.1	83.0	83.8
9.0	77.5	77.3	79.3	79.1	79.0	80.3	79.3	79.0	80.4	80.1	80.0	80.5	79.9	79.8	80.8
10.0	74.0	74.0	75.8	76.2	76.0	77	76.5	76.2	77.3	76.6	76.5	77.5	77.1	77.0	77.9
11.0	70.7	70.5	72.4	72.5	72.3	73.8	73.5	73.2	74.2	73.5	73.2	74.5	74.3	74.0	75.0
12.0	67.0	66.9	69.1	69.5	69.4	70.7	70.1	70.0	71.2	70.8	70.7	71.6	71.8	71.7	72.2
13.0	64.6	64.2	65.9	66.3	66.0	67.7	67.6	67.4	68.4	67.7	67.6	68.8	68.8	68.7	69.6
14.0	61.6	61.4	63.0	63.7	63.5	64.9	64.8	64.5	65.7	65.3	65.3	66.2	66.1	66.0	67.0
15.0	58.4	58.2	60.0	61.2	61.0	62.1	62.2	62.0	62.9	62.7	62.6	63.5	63.4	63.2	64.4
16.0	55.8	55.6	57.4	58.2	58.0	59.5	59.5	59.4	60.4	59.9	60.0	61.0	61.2	61.0	61.9
17.0	53.5	53.3	54.8	56.1	56.0	57	57.1	57.0	58.0	58.0	58.0	58.6	59.0	59.0	59.6
18.0	51.1	51.0	52.4	53.5	53.2	54.6	54.9	54.7	55.6	55.6	55.5	56.3	56.7	56.4	57.4
19.0	48.8	48.4	50.1	51.1	51.0	52.3	52.6	52.3	53.4	53.1	53.0	54.1	54.4	54.2	55.2
20.0	46.6	46.5	47.8	48.9	48.7	50	50.5	50.4	51.2	51.1	51.0	52.0	52.6	52.3	53.1
22.0	42.5	42.3	43.6	44.9	44.8	45.8	46.2	46.0	47.1	47.3	47.0	48.0	48.5	48.2	49.1
24.0	38.8	38.3	40.0	41.4	41.0	42.1	42.7	42.5	43.4	43.7	43.5	44.3	44.8	44.6	45.4
26.0	35.3	35.0	36.5	37.6	37.4	38.6	39.2	39.0	39.9	40.1	40.0	40.8	41.5	41.3	41.9
28.0	32.0	32.0	33.4	34.4	34.3	35.5	35.9	35.6	36.8	36.6	36.6	37.7	38.6	38.3	38.8
30.0	29.5	29.3	30.5	31.7	31.0	32.6	33.3	33.1	33.9	34.0	34.0	34.8	35.5	35.3	35.9

the 6MV at d_{max} compared with data calculated by using the planning systems Precise Plan.

Figure 12 shows the measured beam profiles for the 15MV at d_{max} compared with data calculated by using the planning systems Precise Plan.

DISCUSSION

The central axis percentage depth dose measurements

Results show that percentage depth dose curves for all field sizes (from 1x1 to 40x40 cm^2) are characterized by the buildup of dose at the surface reaching a maximum dose at depth (d_{max}) equal to 1.6 ± 0.1 for 6 MV x-ray and 2.8 ± 0.1 for 15 MV then the dose decrease as the photon beam travels through the phantom beyond d_{max}, which indicates that d_{max} value depends on the energy of the irradiating beam. In addition, it is obvious that beyond d_{max} the PDD increases as the field size increases which is due to the increasing in scattered radiation at larger field sizes.

Also collected data show that for 6 MV the PDD reaches the maximum value at depth d_{max} equal to 1.6 cm while for 15 MV the PDD reaches the maximum value at depth 2.8, and for 6MV, the PDD decreases to 50% at depths 14.5cm, 15.5cm, 16.5cm, 17.5cm and 18.5 cm for field sizes 5x5, 10x10, 15x15, 20x20, and 30x30 cm^2 respectively while for 15 MV the PDD decreases to 50% at depths 18.5cm, 19.5cm, 20.5cm, 20.7cm and 21.5cm for the same filed sizes.

So we can conclude that the PDD decreases with increasing of beam energy from 6 MV to 15 MV at depths from 0 to 2 cm and after that depth it increases

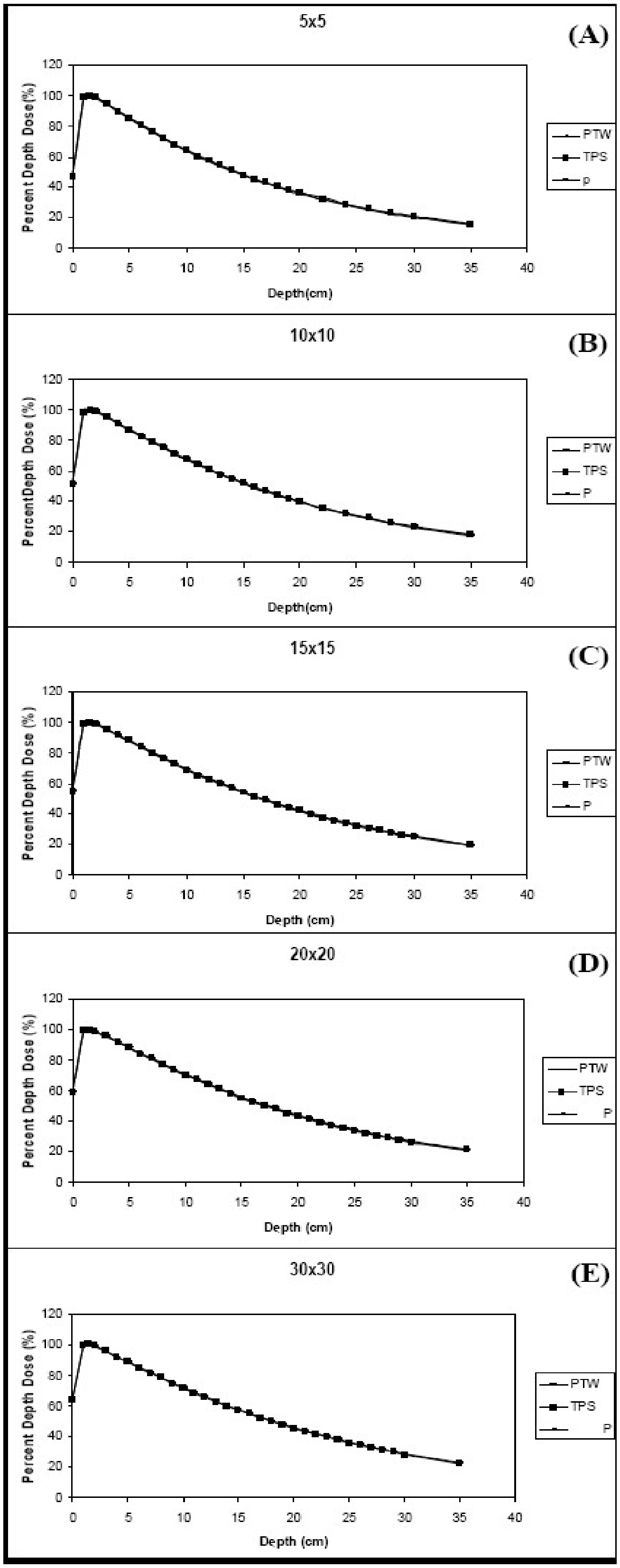

Figure 9 : Measured PDD for 6 MV photon beam emerged from Elekta Precise™ linac. at FSD =100cm in water phantom, compared with calculated and published[7] PDD. of open square field size: (A) 5x5 cm^2, (B) 10x10 cm^2, (C) 15x15 cm^2, (D) 20x20 cm^2 and (E) 30x30 cm^2.

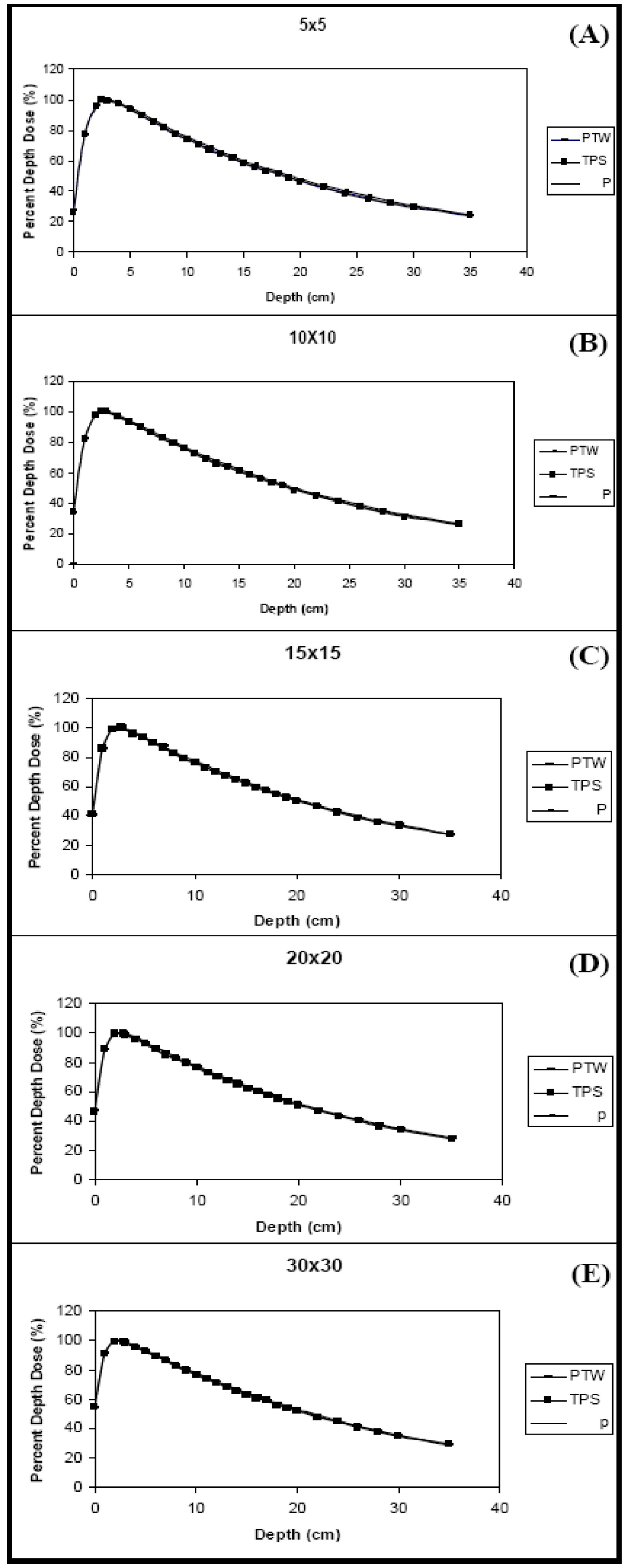

Figure 10 : Measured PDD for15 MV photon beam emerged from Elekta Precise™ linac. at FSD =100cm in water phantom, compared with calculated and published[6] PDD. of open square field size: (A) 5x5 cm^2, (B) 10x10 cm^2, (C) 15x15 cm^2, (D) 20x20 cm^2 and (E) 30x30 cm^2.

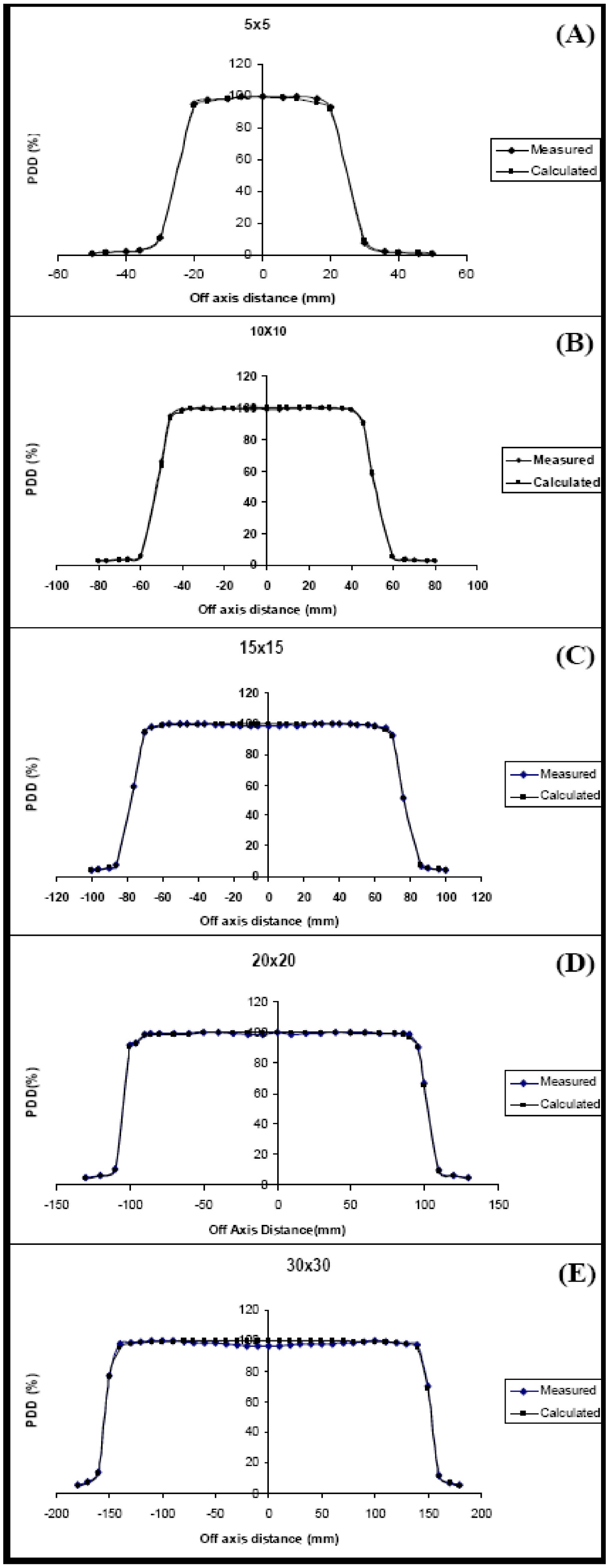

Figure 11 : Measured cross-beam profiles for 6 MV photon beam emerged from Elekta Precise™ linac. at depth d_{max} compared with calculated one for field size: (A) 5x5 cm^2, (B) 10x10 cm^2, (C) 15x15 cm^2, (D) 20x20 cm^2 and (E) 30x30 cm^2.

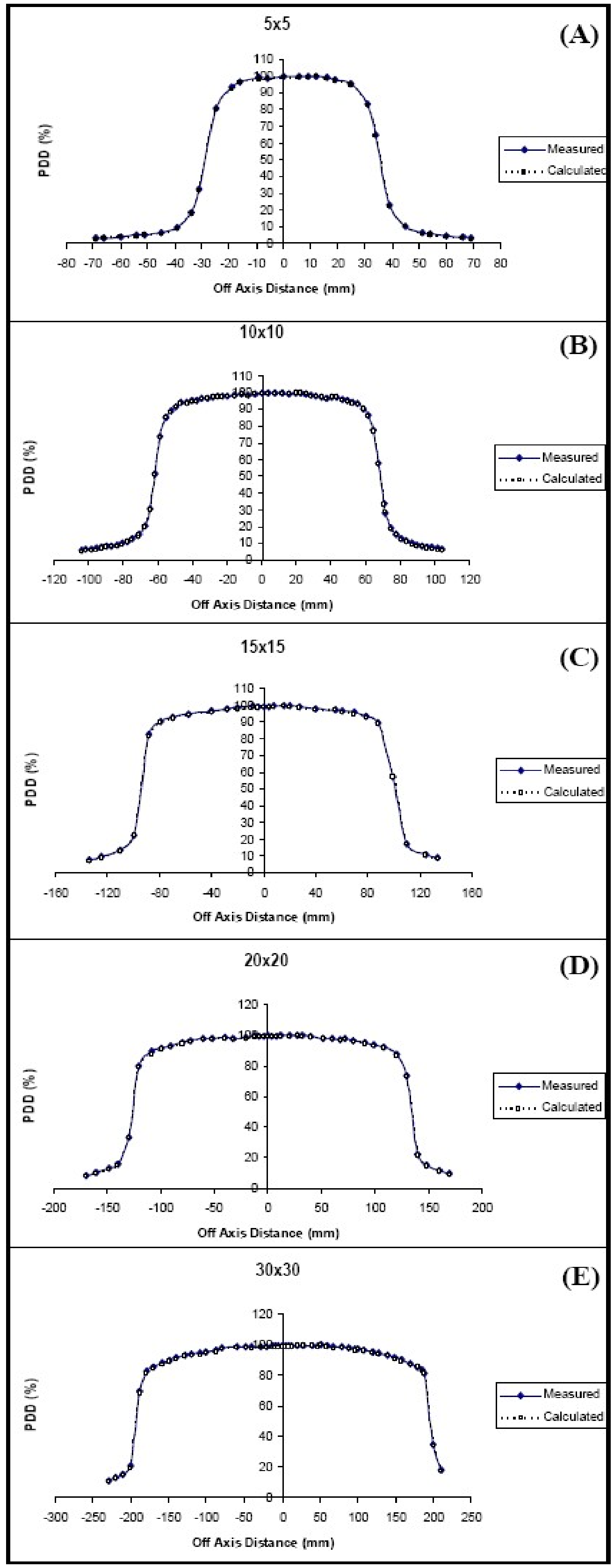

Figure 12 : Measured cross-beam profiles for 15 MV photon beam emerged from Elekta Precise™ linac. at depth d_{max} compared with calculated one for field size: (A) 5x5 cm^2, (B) 10x10 cm^2, (C) 15x15 cm^2, (D) 20x20 cm^2 and (E) 30x30 cm^2.

with increasing of beam energy.

Beam profile measurements for elekta precise™ linac

Results show that for 6 MV photon beam, it is clear that for field sizes 5x5,10x10, 15x15, 20x20 and 30x30cm^2 the homogeneity increased from 0.66% at depth 1.6 cm to 1.58% at depth 20 cm, and increased from 0.88% at depth 1.6 cm to 3.43% at depth 20cm, and increased from 0.90% at depth 1.6cm to 3.99% at depth 20cm and increased from 0.91% at depth 1.6cm to 4.08% at depth 20cm and 1.01% at depth 1.6 cm to 5.31% at depth 20cm respectively. While for 15 MV photon beam for the same field sizes the homogeneity increased from 1.78% at depth 2.8 cm to 2.89% at depth 20 cm, and increased from 2.07% at depth 2.8 cm to 3.77% at depth 20cm,and increased from 1.39% at depth 2.8 cm to 3.29% at depth 20cm,and increased from 1.45% at depth 2.8 cm to 3.51% at depth 20cm, and increased from 1.84% at depth 2.8 cm to 4.51% at depth 20cm respectively. So we can conclude that the beam homogeneity increases with the field size and depth.

For the penumbra analysis, results show that for 6 MV photon beam the penumbra width varies from 5.61 mm at 1.6 cm depth to 7.0 mm for 5x5 cm^2 field size, for field size, 10x10cm^2, the penumbra varied from 5.81 mm to 8.66 mm, for 15x15 cm^2 field size, the penumbra varied from 7.20 mm to 11.78 mm, for 20x20 cm^2 field size, the penumbra varied from 7.80 mm to 13.9 mm, and for 30x30 cm^2 field size, the penumbra varied from 8.32 mm to 18.08 mm. while for 15MV photon beam it show that the penumbra width varies from 7.11 mm at 2.8 cm depth to 8.22 mm for 5x5 cm^2 field size, for field size 10x10cm^2, the penumbra varied from 7.38 mm to 9.91 mm, for 15x15 cm^2 field size, the penumbra varied from 7.56 mm to 10.77 mm, for 20x20 cm^2 field size, the penumbra varied from 7.59 mm to 11.5 mm, and for 30x30 cm^2 field size, the penumbra varied from 7.7 mm to 12.86 mm. so from these results we can see that for deferent field sizes, the penumbra width increases linearly with increasing of the depth.

For TMR studying it is found that, TMR at a given depth increases with the increasing of field size, and there is steep drop of TMR value with the depth at a given field size. TMR is based on the assumption that, the scatter contribution to the depth dose at point independent of the divergence of the beam and depends only on the field size at the point and the depth of the overlying tissue[8]. Also the mean difference and standard deviation between published and measured TMR for 6 MV and 15 MV energies for open field sizes from 5x5 cm^2 to 30x30 cm^2, the maximum and minimum standard deviations were ±0.09 and ±0.11 for 6MV, ±0.08 and ±0.12 for 15MV, which are in compliance with the published tolerances (±2).

Finally results show that the output factor increases with increasing of field size.

Dosimetric verification for photon beam

The central axis PDD results show that for 6 MV photon beam there are a mean difference and a standard deviation in percentage equal to (0.16±0.32), (0.12± 0.52), (0.34±0.24), (0.28±0.29) and (0.32±0.24) for field sizes (5x5), (10x10), (15x15), (20x20) and (30x30) cm^2 respectively between the measured and the calculated data, and there are a mean difference and a standard deviation in percentage equal to (0.18±0.98), (0.24± 0.74), (0.26±0.62), (0.16±0.42) and (0.12±0.30) for field sizes (5x5), (10x10), (15x15), (20x20) and (30x30) cm^2 respectively between the measured and the published data[7,8]. While for 15 MV photon beam there are a mean difference and a standard deviation in percentage equal to (0.22±0.13), (0.24 ±0.15), (0.21±0.09), (0.14±0.15) and (0.17±0.13) for field sizes (5x5), (10x10), (15x15), (20x20) and (30x30) cm^2 respectively between the measured and the calculated data, and there are a mean difference and a standard deviation in percentage equal to (1.26±0.37), (0.94± 0.31), (0.78±0.18), (.84±0.24) and (0.62±0.20) for field sizes (5x5), (10x10), (15x15), (20x20) and (30x30) cm^2 respectively between the measured and the published data[7,8]. So we can conclude that the measured data for both 6 MV and 15 MV photon beam are in a good agreement with the calculated and the published data[7,8].

Finally the cross-beam profile results show that for 6 MV photon beam the maximum and minimum standard deviations between the calculated data from (TPS) and measured data were ±1.7 and ±0.7, while for 15 MV photon beam the maximum and minimum standard deviations between the calculated data from (TPS) and measured data were± 0.36 and ±0.23, so we can see that the differences between the calculated cross-beam profiles data and measured cross-beam profiles data are in the accepted range of ±2%.

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