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Electron Beams Commissioning and Initial Measurements on an Elekta Synergy Platform Linear Accelerator

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Abstract

A linear accelerator (Linac) must be commissioned for use in treating cancer patients. This research work aims to analyze part of the electron beam data produced by the Elekta Synergy Platform Linac at the radiotherapy department at Tripoli University Hospital, Tripoli, Libya. In thispaper, percentage depth dose (PDD), beam profile and applicators factor were studied at five different electron beam energies (4, 6, 8, 10 and 12 MeV). The relative measurement part of this study was carried out using a PTW MP3-M 3D water scanning system, and the absolute measurement was taken using a plane parallel ionization chamber and a unidose E electrometer. The analysis for these measurements has yielded the following results: a) The Penetrative qualities of all the electron beam energies were within the manufacturer's tolerance limits of ±1%; b) the maximum values of beam flatness of 2.94 and beam symmetry of 1.93 are within the accepted limits of International Electrotechnical Commission criteria; c) A penumbra maximum value of 1.30 was measured at the 4-MeV electron beam energy and using a 14×14 cm^2 applicator size. All the obtained parameters were within the permissible limits. Therefore, the electron beams can be safely used forclinical purposes.

Keywords: Elekta Synergy Platform; Electron Beam Commissioning; PDD; Beam Profile; Applicator Factor.

INTRODUCTION

One common treatment method for cancer disease is radiotherapy. It uses high-energy radiation of different ionization types to destroy tumor cells. The type of treatment radiation depends on tumor size and location, tumor type, and tumor stage. For superficial tumors, electron beams are widely used due to their sharp dose fall-off and relatively short range of particles in tissue (Arunkumar et al., 2010). A linear accelerator is the most common and most sophisticated machine used for external beam radiotherapy made by different manufacturers. Linacs of different manufacturers have different structure order and design especially in Linacs treatment head. The differences in the treatment head affect the characteristics of electron and photon beams. Moreover, Linacs of the same manufacturer are slightly different in their beam characteristics (Brahme et al., 1976; Khan, 1991; IEC, 1984; Varatharaj et al., 2016).

Accurate data measurements of photon and electron beam characteristics produced by Linac, which need to be transferred into the Treatment Planning System (TPS) to predicate the radiation dose distribution inside the patient, are important factors that affect the success of radiation therapy (Acqah *et al*., 2014). According to the recommendations of the American Association of Physicists in Medicine (AAPM) in the Task Group 40, and International Commission on Radiation Units and Measurements in report 50 (Kutcher et al., 1994; ICRU, 1993), the dose delivery to tumor should be within ±5% of a prescribed dose. Therefore, commissioning and acceptance tests of the linear accelerator are required before setting the machine in clinical-use (Khan, 2010; Sahool et al., 2012).

Due to the lack of local standards of measurement, this paper aims to present and analyze part of electron beams commissioning to allow physicists of other institutes to compare their results with those of this study. The measurements include the percentage depth dose curves, beam profiles parameters and applicators factor of an Elekta Synergy platform linear accelerator released by Elekta Oncology Systems, Crawley, UK.

MATERIALS AND METHODS

This work was carried out at Radiotherapy Department, Tripoli University Hospital in Tripoli, Libya. Measurements of percentage depth dose (PDD), beam profile and applicators factor were carried out for electron beam of nominal energies 4, 6, 8, 10 and 12 MeV generated by Elekta Synergy platform linear accelerator. The dosimetry system for measurements of PDD and beam profile was a PTW MP3-M 3D water scanning system (PTW, Freiburg, Germany). The system consists of a water tank of inner size 59.6×59.4×50.25 cm^3, a TANDEM electrometer, a TBA control unit and two 0.125 cm^3semiflex ionization chambers for both reference and ionization field. The measured PDD and beam profile were collected using PTW MEPHYSTO mc^2 navigation software (PTW, Freiburg) version 1.6. Applicators factors were measured in polystyrene slab phantom at depth of the maximum dose using a plane parallel ionization chamber connected to PTW Unidose E electrometer at a source to surface distance (SSD) of 100 cm.

PDD and beam profiles were measured at (SSD) of 100 cm setup and at gantry and collimator angles of 0^o. The applicators used for these measurements were of size 6×6 cm^2, 10×10 cm^2, 14×14 cm^2 and 20×20 cm^2 in different depths according to the electron beam applied and taking into account the bremsstrahlung contamination in the beam. All measurements were made according to TRS-277 and TRS-398 (IAEA, 1987; IAEA, 2000).

Parameters calculated from the central axis PDD according to AAPM Task Group 25 (Gerbi et al., 2009) are the mean energy $\bar{E}_0$and the most probable energy $E_{p,0}$ at the water phantom surface using equations (1) and (2) respectively:

$$\bar{E}_0 = 2.33\, R_{50} \qquad (1)$$
$$E_{p,0} = 0.22 + 1.98R_p + 0.0025\, R_p^2 \qquad (2)$$

Where R_{50} is the depth at which the dose is 50% of the maximum, and R_p is the practical range. Another important parameter is dose gradient (G), which measures how quickly the dose decreases beyond the therapeutic range and is given by equation (3) (Gerbi et al., 2006; Podgorsak ,2003)

$$G = \frac{R_p}{R_p - R_q} \qquad (3)$$

Where R_q is the depth at which the tangent through the dose inflection point intersects the maximum dose level. For electron beams with mean energy of 5 MeV – 30 MeV, the lower limit of G is 2.3 (Kirby et al., 1985; Jamshidi et al., 1987).

Beam flatness, beam symmetry and penumbra width were calculated based on measurements of beam profiles. The IEC 60976 (IEC, 2007) criteria were followed for flatness, symmetry and penumbra width calculation.

RESULTS

Penetrative quality: The penetrative quality of the electron beam is defined as the depth of the 80% point to the maximum absorbed dose on the central beam axis. Table 1 shows the results of declared and measured electron beam penetrative quality which measured at $\mathrm{SSD} = 100\ cm$ for the applicator of size 14×14 cm.

Table (1). Declared and measured values of penetrative quality of electron beams.

Nominal energy (MeV)	Penetrative quality		Difference mm
	Declared Mm	measured mm	
4	13.30	13.55	-0.25
6	20.00	19.82	+ 0.18
8	26.70	26.32	+ 0.38
10	33.30	33.64	- 0.34
12	40.00	40.20	- 0.20

Percentage depth dose: Figure 1 illustrates the percentage depth dose curves of 4, 6, 8, 10 and 12 MeV electron beam energies for the applicator of size 10×10 cm^{2}at $\mathrm{SSD} = 100\ cm$.

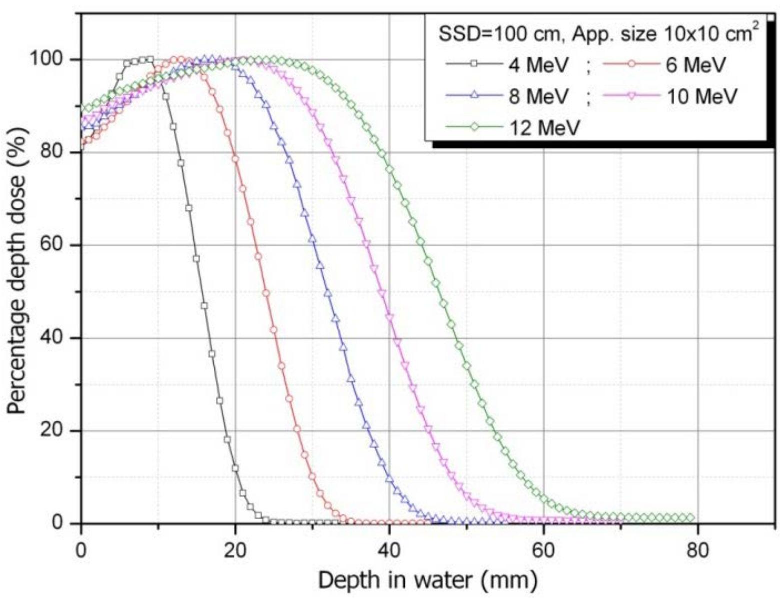

Figure (1). PDD curves of 4, 6, 8, 10 and 12 MeV electron energies for the applicator of size 10×10 cm2 at SSD 100 cm

Electron beams parameters R_{50}, R_{80}, R_{100}, R_p, R_q, percentage surface dose D_s and bremsstrahlung contamination D_x obtained from the measured PDD at SSD of 100 cm are presented in Table 2.

Table 3 presents the calculated parameters from the measured (PDD) data for the electron beam of energies 4, 6, 8, 10 and 12 MeV and applicators of size $6 \times 6\ cm^2$, $10 \times 10\ cm^2$, $14 \times 14\ cm^2$ and $20 \times 20\ cm^2$.

Table (2). Electron beam parameters obtained from PDD at $SSD = 100\ cm$.

App. Size cm^2	R_{50} mm	R_{80} mm	R_{90} mm	R_{100} mm	R_p mm	R_q mm	D_s %	D_x %
Electron nominal energy : 4 MeV								
6×6	16.00	12.98	11.56	8.00	20.53	11.91	79.32	0.21
10×10	15.69	12.70	11.31	8.00	19.87	11.22	81.25	0.19
14×14	16.61	13.55	12.16	9.00	20.67	12.00	80.78	0.17
20×20	16.87	13.81	12.39	9.00	21.16	12.57	81.43	0.11
Electron nominal energy : 6 MeV								
6×6	23.43	19.27	17.32	12.00	29.35	17.47	81.50	0.27
10×10	23.93	19.75	17.80	12.00	30.29	17.62	82.32	0.35
14×14	24.02	19.82	17.87	12.00	30.29	17.56	82.95	0.34
20×20	24.22	20.00	17.92	12.00	30.53	17.83	84.30	0.52
Electron nominal energy : 8 MeV								
6×6	30.69	25.82	23.24	17.00	37.63	24.09	84. 62	0.61
10×10	31.91	26.54	24.03	17.00	38.57	23.77	85.27	0.38
14×14	31.73	26.32	23.74	17.00	39.86	24.35	85.49	0.71
20×20	31.72	26.33	23.76	17.00	39.48	24.48	87.04	0.52
Electron nominal energy : 10 MeV								
6×6	39.09	32.64	29.63	21.00	47.55	30.57	86.55	0.63
10×10	38.95	32.61	29.47	21.00	46.29	30.58	87.03	0.84
14×14	40.03	33.64	30.50	21.00	47.71	31.38	87.17	0.66
20×20	39.94	33.54	30.40	21.00	47.32	31.07	88.22	0.47
Electron nominal energy : 12 MeV								
6×6	46.28	38.62	34.75	25.00	56.69	35.43	89.55	1.11
10×10	46.43	38.93	35.15	25.00	56.42	35.20	89.61	1.44
14×14	47.77	40.20	36.40	25.00	56.57	36.25	89.13	1.28
20×20	47.50	39.98	36.26	25.00	55.90	36.59	90.38	1.03

Table (3). Electron beam parameters calculated by PDD at $SSD = 100\ cm$.

App. Size (cm^2)	$E_{p,0}$ (MeV)	$\bar{E}_0$ (MeV)	G	%error$E_{p,0}$& Nominal Energy
Electron nominal energy : 4 MeV				
6×6	4.19	3.73	2.38	-4.81
10×10	4.05	3.66	2.30	-1.37
14×14	4.22	3.87	2.38	-5.54
20×20	4.32	3.93	2.46	-8.09
Electron nominal energy : 6 MeV				
6×6	6.05	5.46	2.47	-0.81
10×10	6.25	5.57	2.39	-4.15
14×14	6.25	5.60	2.38	-4.15
20×20	6.30	5.64	2.40	-4.99
Electron nominal energy : 8 MeV				
6×6	7.83	7.15	2.78	2.17
10×10	8.03	7.44	2.61	-0.38
14×14	8.31	7.39	2.57	-3.89
20×20	8.23	7.39	2.63	-2.85
Electron nominal energy : 10 MeV				
6×6	10.00	9.11	2.80	-0.02
10×10	9.72	9.08	2.95	2.77
14×14	10.04	9.33	2.92	-0.38
20×20	9.95	9.31	2.91	0.49
Electron nominal energy : 12 MeV				
6×6	12.05	10.78	2.67	-0.42
10×10	11.99	10.82	2.66	0.09
14×14	12.02	11.13	2.78	-0.19
20×20	11.87	11.07	2.89	1.07

The relation between the mean energy $\bar{E}_0$ and R_{50} is illustrated in Figure 2.

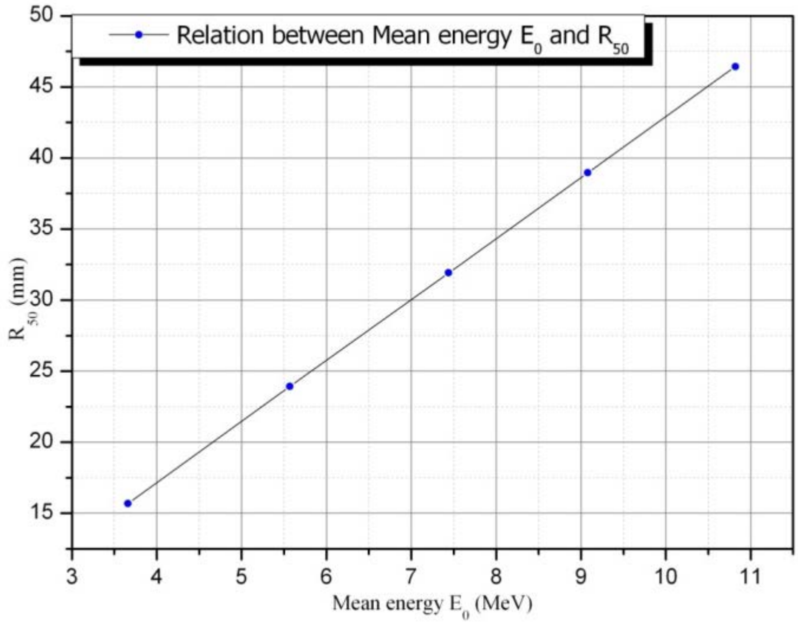

Figure (2). The relation between $\bar{E}_0$ and R_{50}

Beam profiles:

Figures 3, 4, 5 and 6 illustrate selected beam profiles for energies 4 MeV and applicator size 6×6 cm^2, 6 MeV and applicator size 10x10 cm^2, 10 MeV and applicator size 20×20 cm^2, and 12 MeV and applicator size 14×14 cm^2, respectively.

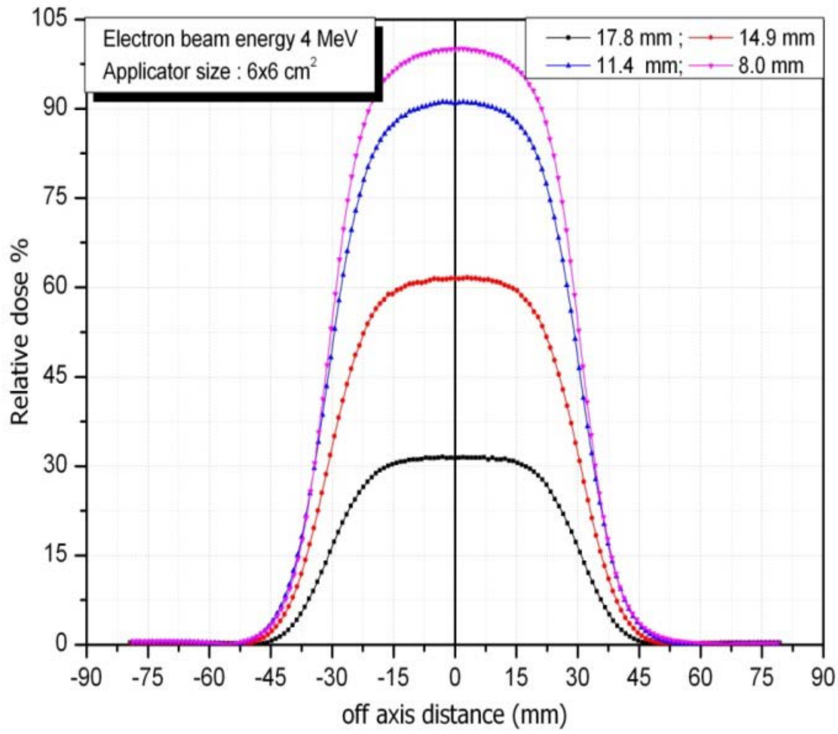

Figure (3). Beam profile for 4 MeV electron beam and applicator of size 6×6 cm^2

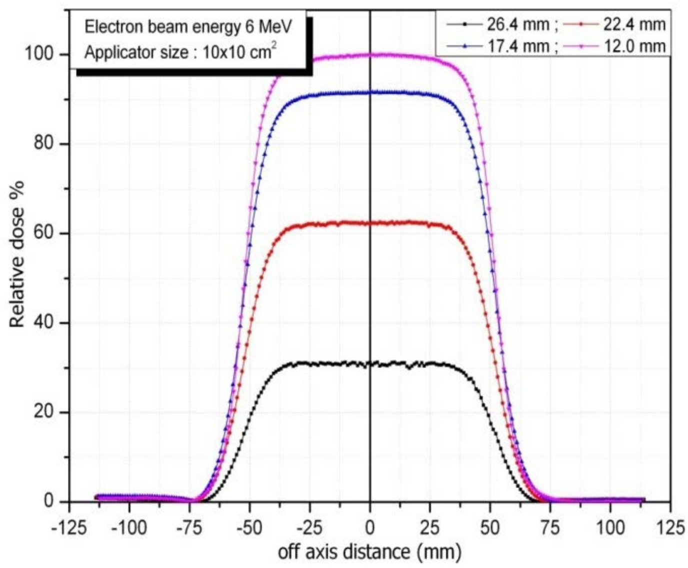

Figure (4). Beam profile for 6 MeV electron beam and applicator of size 10×10 cm^2.

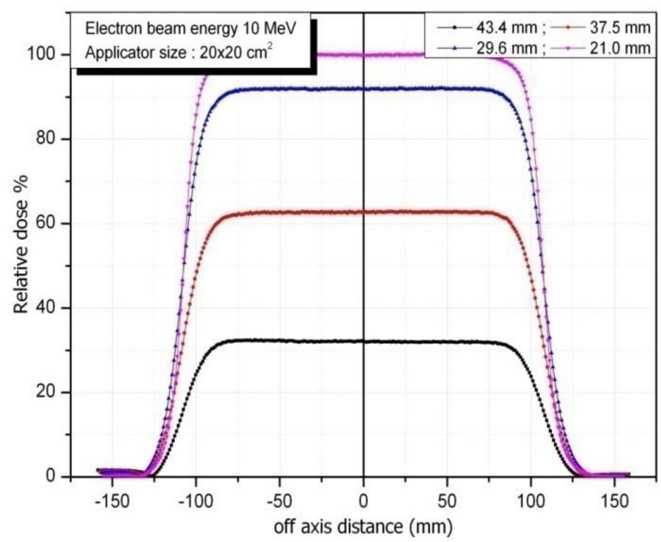

Figure (5): Beam profile for 10 MeV electron beam and applicator of size 20×20 cm^2.

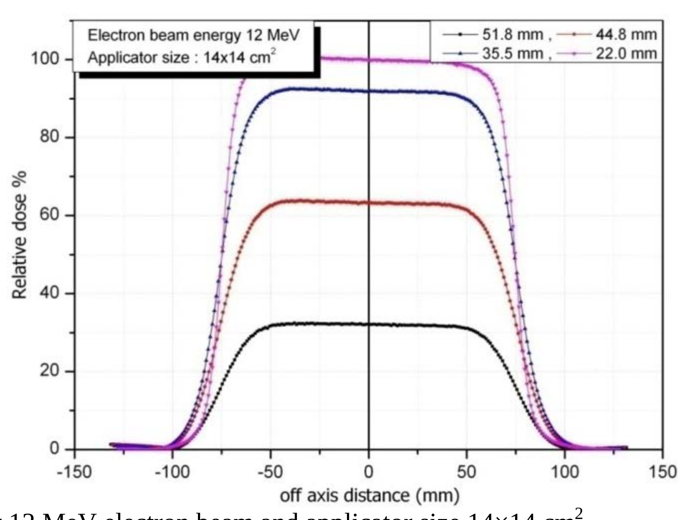

Figure (6). Beam profile for 12 MeV electron beam and applicator size 14×14 cm^2.

The characteristics of beam profiles (beam flatness, beam symmetry and penumbra) for electron beam energies 4, 6, 8, 10 and 12 MeV using two applicators of size 14×14 cm^2 and 20×20 cm^2 are tabulated in Table 4.

Table (4). Beam profiles characteristics of the electron beam

App. size (cm^2)	Flatness %	Symmetry %	Penumbra width (cm)	
			L	R
Electron beam energy: 4 MeV				
14×14	2.94	1.93	1.28	1.30
20×20	2.23	0.12	1.23	1.27
Electron beam energy: 6 MeV				
14×14	2.14	0.22	1.19	1.20
20×20	1.14	1.33	1.14	1.14
Electron beam energy: 8 MeV				
14×14	2.59	0.05	1.12	1.14
20×20	1.81	0.74	1.09	1.11
Electron beam energy: 10 MeV				
14×14	2.23	1.82	1.17	1.19
20×20	1.10	0.03	1.13	1.14
Electron beam energy: 12 MeV				
14×14	2.39	0.47	1.01	1.03
20×20	1.67	1.14	0.96	0.97

Applicators factors:

Applicator factor defines the ratio of output of the utilized applicator to the output of the reference applicator (10×10 cm^2). Table 5 represents the applicator factors measured at the depth of dose maximum and SSD=100 cm.

Table (5). Applicators factor of energies 4, 6, 8, 10 and 12 MeV electron beams.

Applicator size (cm^2)	Electron energy (MeV)				
	4	6	8	10	12
6×6	0.847	0.934	0.956	0.976	0.984
10×10	1.000	1.000	1.000	1.000	1.000
14×14	1.041	1.013	0.987	0.977	0.982
20×20	1.036	1.018	0.994	0.965	0.976

DISCUSSION

The maximum deviation of the measured value from the declared value of penetrative quality should be ±1 mm as recommended by manufacturer customer acceptance tests (Elekta, 2007). The results showed that the maximum deviation was 0.37 mm, which occurred for 8 MeV nominal energy. This is within the acceptable limit of ±1 mm. As shown in Figure 1, the measured PDD is increased with electron beam energy and is decreased with depth. The rapidness of the radiation dose is a decreasing function of electron beam energy while the magnitude of bremsstrahlung contamination is an increasing function of electron beam energy.

The bremsstrahlung contamination to the central axis percentage depth dose, $D_x\%$, was less than 0.55% of the maximum dose for electron beam of energies 4 MeV - 8 MeV, 0.84% for 10 MeV and

1.44% for electron beam of energy 12 MeV. These percentages are within the tolerance limits of 1% for electron beam energy 4 MeV, and 4% for electron beam energy 20 MeV (Podgorsak, 2003). Table 3 shows that the most probable energy $E_{p,0}$ is higher than the mean energy $\bar{E}_0$ due to the spread of the electron beam spectrum. The tolerance limit between calculated most probable energy and nominal energy is ±5% (Chosdu, et al., 1995). Thus, the calculated most probable energies are in agreement with the tolerance limit except electron beam of energy 4 MeV and applicator of sizes 14×14 cm^{2},and 20×20 cm^2 which exceeded the tolerance limit. Furthermore, the values of dose gradient G for all electron beam energies agree with the lower limit of 2.3.

The relation between mean energy $\bar{E}_0$ and R_{50} is linear and is in agreement with the theoretical results of Monte Carlo calculations (HPA, 1975).

The values of beam flatness and symmetry were calculated according to International Electrotechnical Commission (IEC) (IEC, 1997). The tolerance limits of flatness and symmetry are ±3% and ±2%, respectively. It is noticeable that the values of flatness decrease as applicator size increases which means that the values of flatness are field size dependent. The highest value of flatness was 2.94% for electron beam energy 4 MeV and applicator size 14×14 cm^2, whereas the lowest value was 1.10% for electron beam energy 10 MeV and applicator size 20×20 cm^2. The values of flatness meet the tolerance limit of ±3%. The values of symmetry range from 0.03% to 1.93%. This means that the values of symmetry for all energies and two applicators of size 14×14 cm^2 and 20×20 cm^2 are well in agreement with the manufacturer's specifications and IEC.

Table 4 also shows that the penumbra width is an electron energy and field size dependent. The penumbra width is a decreasing function of electron beam energy and field size. The maximum recorded value of the penumbra was 1.30 cm for electron beam energy 4 MeV and applicator size 14×14 cm^2, while the minimum recorded value of the penumbra was 0.96 cm for electron beam energy 12 MeV and applicator size 20×20 cm^2.

The results of applicator factor show that the applicator factor is increased as the applicator size increased for energies 4 and 6 MeV, whereas for energies 8, 10 and 12 MeV is decreased as the applicator size increased. The results are in agreement with Varian TrueBeam and Elekta Versa HD studies (Glide et al., 2013; Narayanasamy et al., 2016).

CONCLUSION

In this work, the electron beams commissioning of an Elekta Synergy platform linear accelerator were presented and analyzed. The results show that the penetrative quality for all electron beam energies were within the tolerance limit of ±1 mm. Bremsstrahlung contamination obtained from measured (PDD) was less than 1.5% for electron beam of nominal energy of 12 MeV which is within the tolerance limits. Values of dose gradient G meet the lower limit of 2.3. The relation between the mean energy $\bar{E}_0$ and R_{50} is linear, and the percentage error between the most probable energy $E_{p,0}$ and nominal energy fall within the ±5%limit. Beam flatness and beam symmetry, which characterized the beam profiles, meet the IEC 60731 tolerance. The penumbra width is a decreasing function of electron beam energy. The maximum value of the penumbra recorded was 1.30 cm for 4 MeV, whereas the minimum value was 0.96 cm. for 12 MeV. Finally, it is concluded that the measured data of all electron beam energies were found to be within permissible limits. Therefore, all energies of the electron beam can safely be used for clinical purposes.

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